SAE Aerospace
An SAE International Group

AEROSPACE MATERIAL SPECIFICATION

SAE AMS6411G

Issued 1969-03
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Superseding AMS6411F

Steel Bars, Forgings, and Tubing
0.88Cr – 1.8Ni – 0.42Mo – 0.08V (0.28 – 0.33C) (4330 Mod)
Consumable Electrode Remelted

(Composition similar to UNS K23080)

RATIONALE

AMS6411G is an update of this specification.

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

These products have been used typically for parts requiring high tensile strength and good ductility with relatively high impact strength, superior transverse properties, and hardness, but usage is not limited to these applications. Certain design and processing procedures may cause these products to become susceptible to stress-corrosion cracking after heat treatment. ARP1110 recommends practices to minimize such conditions.

2. APPLICABLE DOCUMENTS

The issue of the following documents in effect on the date of the purchase order forms a part of this document to the extent specified 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), www.sae.org.

AMS2251	Tolerances, Low-Alloy Steel Bars
AMS2253	Tolerances, Carbon and Alloy Steel Tubing
AMS2259	Chemical Check Analysis Limits, Wrought Low-Alloy and Carbon Steels
AMS2300	Steel Cleanliness, Premium Aircraft-Quality Magnetic Particle Inspection Procedure
AMS2310	Qualification Sampling of Steels, Transverse Tensile Properties
AMS2370	Quality Assurance Sampling and Testing, Carbon and Low-Alloy Steel Wrought Products and Forging Stock
AMS2372	Quality Assurance Sampling and Testing, Carbon and Low-Alloy Steel Forgings

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

SAE values your input. To provide feedback on this Technical Report, please visit
http://www.sae.org/technical/standards/AMS6411G

AMS2806 Identification, Bars, Wire, Mechanical Tubing, and Extrusions, Carbon and Alloy Steels and Heat and Corrosion-Resistant Steels and Alloys
AMS2808 Identification, Forgings
AS1182 Standard Stock Removal Allowance, Aircraft-Quality and Premium Aircraft-Quality Steel Bars and Mechanical Tubing

ARP1110 Minimizing Stress Corrosion Cracking in Wrought Forms of Steels and Corrosion-Resistant Steels and 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, www.astm.org.

ASTM A 255 End-Quench Test for Hardenability of Steel
ASTM A 370 Mechanical Testing of Steel Products
ASTM A 604 Macroetch Testing of Consumable Electrode Remelted Steel Bars and Billets
ASTM E 112 Determining Average Grain Size
ASTM E 350 Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron, and Wrought Iron
ASTM E 384 Microindentation Hardness of Materials

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 350, by spectrochemical methods, or by other analytical methods acceptable to purchaser.

TABLE 1 - COMPOSITION

Element	min	max
Carbon	0.28	0.33
Manganese	0.65	1.00
Silicon	0.15	0.35
Phosphorus	--	0.015
Sulfur	--	0.015
Chromium	0.75	1.00
Nickel	1.65	2.00
Molybdenum	0.35	0.50
Vanadium	0.05	0.10
Copper	--	0.35

3.1.1 Check Analysis

Composition variations shall meet the applicable requirements of AMS2259.

3.2 Melting Practice

Steel shall be multiple melted using either electroslag remelting (ESR)practice or consumable electrode vacuum arc remelting (VAR) practice as the final melting process.

3.3 Condition

The product shall be supplied in the following condition; hardness and tensile strength shall be determined in accordance with ASTM A 370:

3.3.1 Bars

3.3.1.1 Bars 0.500 Inch (12.70 mm) and Under in Nominal Diameter or Least Distance Between Parallel Sides

Cold finished having tensile strength not higher than 130 ksi (896 MPa), or equivalent hardness (See 8.2).

3.3.1.2 Bars Over 0.500 Inch (12.70 mm) in Nominal Diameter or Least Distance Between Parallel Sides

Hot finished, and annealed if necessary, unless otherwise ordered, having hardness not higher than 241 HB, or equivalent (See 8.3). Bars ordered cold finished may have hardness as high as 248 HB, or equivalent (See 8.3).

3.3.2 Forgings

Normalized and tempered having hardness not higher than 269 HB, or equivalent (See 8.3).

3.3.3 Mechanical Tubing

Cold finished, unless otherwise ordered, having hardness not higher than 25 HRC, or equivalent (See 8.3). Tubing ordered hot finished and annealed shall have hardness not higher than 99 HRB, or equivalent (See 8.3).

3.3.4 Forging Stock

As ordered by the forging manufacturer.

3.4 Properties

The product shall conform to the following requirements; hardness and tensile testing shall be performed in accordance with ASTM A 370:

3.4.1 Macrostructure

Visual examination of transverse full cross-sections from bars, billets, tube rounds, or forging stock, etched in hot hydrochloric acid in accordance with ASTM A 604, shall show no pipe or cracks. Porosity, segregation, inclusions, and other imperfections in product 36 square inches (232 square cm) and under in nominal cross-sectional area shall be no worse than macrographs of ASTM A 604 shown in Table 2.

TABLE 2 - MACROSTRUCTURE LIMITS

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

3.4.2 Average Grain Size

Shall be ASTM No. 5 or finer, determined in accordance with ASTM E 112.

3.4.3 Hardenability

Shall be J 14/16 inch (22 mm) = 49 HRC minimum, and J 24/16 inch (38 mm) = 45 HRC minimum, determined on the standard end-quench test specimen in accordance with ASTM A 255 except that the steel shall be normalized at 1700 °F ± 10 (927 °C ± 6) and the specimen austenitized at 1550 °F ± 10 (843 °C ± 6).

3.4.4 Decarburization

3.4.4.1 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 3.4.4.4.

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

3.4.4.3 Decarburization of bars when 3.4.4.1 or 3.4.4.2 is not applicable shall be not greater than shown in Table 3.

TABLE 3A - MAXIMUM DECARBURIZATION, BARS, INCH/POUND UNITS

Nominal Diameter or Distance Between Parallel Sides Inches	Total Depth of Decarburization Inch
Up to 0.375, incl	0.015
Over 0.375 to 0.500, incl	0.017
Over 0.500 to 0.625, incl	0.019
Over 0.625 to 1.000, incl	0.022
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 to 4.000, incl	0.045

TABLE 3B - MAXIMUM DECARBURIZATION, BARS, SI UNITS

Nominal Diameter or Distance Between Parallel Sides Millimeters	Total Depth of Decarburization Millimeters
Up to 9.52, incl	0.38
Over 9.52 to 12.70, incl	0.43
Over 12.70 to 15.88, incl	0.48
Over 15.88 to 25.40, incl	0.56
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 to 101.60, incl	1.14

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

3.4.4.4 Decarburization of tubing when 3.4.4.1 or 3.4.4.2 is not applicable shall be not greater than shown in Table 4.

TABLE 4A - MAXIMUM DECARBURIZATION, TUBING, INCH/POUND UNITS

Nominal Wall Thickness Inches	Total Depth of Decarburization Inch ID	Total Depth of Decarburization Inch 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 4B - MAXIMUM DECARBURIZATION, TUBING, SI UNITS

Nominal Wall Thickness Millimeters	Total Depth of Decarburization Millimeter ID	Total Depth of Decarburization Millimeters 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

3.4.4.5 Decarburization shall be measured by the metallographic method, by HR30N scale hardness testing method, or by a traverse method using microhardness testing in accordance with ASTM E 384. The hardness method(s) shall be conducted on a hardened but untempered specimen 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 on the adjacent surface. In case of dispute, the depth of decarburization determined using the microhardness traverse method shall govern.

3.4.4.5.1 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.

3.4.5 Response to Heat Treatment

Specimens shall meet the following requirements after being normalized by heating to 1700 °F ± 10 (927 °C ± 6), holding at heat for not less than 1 hour, and cooling in air; hardened by heating to 1550 °F ± 10 (843 °C ± 6), holding at heat for 1 hour ± 0.2, and quenching in oil, and heated to the required tempering temperature, held at heat for not less than 1 hour, and cooled in air.

3.4.5.1 Longitudinal Tensile Properties

Shall be as shown in Table 5; testing in the longitudinal direction need not be performed on product tested in the transverse direction.

TABLE 5 - MINIMUM TENSILE PROPERTIES

Property	Value
Tensile Strength	220.0 ksi (1517 MPa)
Yield Strength at 0.2% Offset	185.0 ksi (1276 MPa)
Elongation in 4D	10%
Reduction of Area	35%

3.4.5.2 Transverse Tensile Properties

Shall be as shown in Table 6, determined on specimens selected and prepared in accordance with AMS2310. Transverse tensile requirements of Table 6 apply only to product that tensile specimens not less than 2.50 inches (63.5 mm) in length can be taken.

TABLE 6A - MINIMUM TENSILE PROPERTIES, INCH/POUND UNITS

Cross-Sectional Area Square Inches	Tensile Strength ksi	Yield Strength at 0.2% Offset ksi	Reduction of Area %, Average	Reduction of Area %, Individual
Up to 144, incl	220.0	185.0	35	30
Over 144 to 225, incl	220.0	185.0	30	25
Over 225	220.0	185.0	25	20

TABLE 6B - MINIMUM TENSILE PROPERTIES, SI UNITS

Cross-Sectional Area Square Centimeters	Tensile Strength MPa	Yield Strength at 0.2% Offset MPa	Reduction of Area %, Average	Reduction of Area %, Individual
Up to 929, incl	1517	1276	35	30
Over 929 to 1452, incl	1517	1276	30	25
Over 1452	1517	1276	25	20

3.5 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.

3.5.1 Steel shall be premium aircraft-quality conforming to AMS2300 except that a maximum average frequency (F) rating of 0.10 and a maximum average severity (S) rating of 0.20 shall apply.

3.5.2 Bars and tubing ordered hot rolled or cold drawn, or ground, turned, or polished shall, after removal of the stock removal allowance in accordance with AS1182, be free from seams, laps, tears, and cracks open to the ground, turned, or polished surface.

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

3.6 Tolerances

Shall be as follows:

3.6.1 Bars

In accordance with AMS2251.

3.6.2 Mechanical Tubing

In accordance with AMS2253.

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

Composition (3.1), condition (3.3), macrostructure (3.4.1), average grain size (3.4.2), hardenability (3.4.3), decarburization (3.4.4), and tolerances (3.6) are acceptance tests and shall be performed on each heat or lot as applicable.