AEROSPACE MATERIAL SPECIFICATION

AMS6411™	REV. K

Issued 1969-03
Reaffirmed 1994-04
Revised 2023-07

Superseding AMS6411J

Steel Bars, Forgings, Mechanical Tubing and Forging Stock
0.88Cr - 1.8Ni - 0.42Mo - 0.08V (0.28 - 0.33C) (4330 Mod)
Consumable Electrode Remelted
(Composition similar to UNS K23080)

RATIONALE

AMS6411K is the result of a Five-Year Review and update of the specification. The revision updates the Title to match the Scope, updates composition reporting (see 3.1.1), clarifies macrostructure requirements (see 3.4.1.1, 3.4.1.2, and 8.8), adds Jominy testing details (see 3.4.3), revises decarburization testing requirements (see 3.4.4.5), clarifies application of strain rate (see 3.4.5.3), prohibits unauthorized exceptions (see 3.7, 4.4.4, and 8.6), adds forging stock properties (see 4.4.3), adds finish information (see 8.5) and allows the use of prior revisions (see 8.7).

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 specification 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.

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
SAE WEB ADDRESS: **http://www.sae.org**

For more information on this standard, visit
https://www.sae.org/standards/content/AMS6411K

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (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 and Testing of Steels for 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

AMS2806 Identification Bars, Wire, Mechanical Tubing, and Extrusions, Carbon and Alloy Steels, and Corrosion and Heat-Resistant Steels and Alloys

AMS2808 Identification, Forgings

ARP1110 Minimizing Stress Corrosion Cracking in Wrought Forms of Steels, and Corrosion Resistant Steels and Alloys

AS1182 Standard Stock Removal Allowance, Aircraft-Quality and Premium Aircraft-Quality Steel, Bars and Mechanical Tubing

AS7766 Terms Used in Aerospace Metals Specifications

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 A255 Determining Hardenability of Steel

ASTM A370 Mechanical Testing of Steel Products

ASTM A604 Macroetch Testing of Consumable Electrode Remelted Steel Bars and Billets

ASTM A751 Chemical Analysis of Steel Products

ASTM E112 Determining Average Grain Size

ASTM E140 Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb Hardness

ASTM E1077 Estimating the Depth of Decarburization of Steel Specimens

2.3 Definitions

Terms used in AMS are defined in AS7766.

3. TECHNICAL REQUIREMENTS

3.1 Composition

Shall conform to the percentages by weight shown in Table 1, determined in accordance with ASTM A751 or by other analytical methods acceptable to the 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 The producer may test for any element not listed in Table 1 and include this analysis in the report of 4.4. Reporting of any element not listed in the composition table is not a basis for rejection unless limits of acceptability are specified by the purchaser.

3.1.2 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 A370:

3.3.1 Bars

Bars shall not be cut from plate (see 4.4.2).

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 HBW, or equivalent (see 8.3). Bars ordered cold finished may have hardness as high as 248 HBW, or equivalent (see 8.3).

3.3.2 Forgings

Normalized and tempered having hardness not higher than 269 HBW, 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 A370:

3.4.1 Macrostructure

Visual examination of transverse full cross sections from bars, billets, tube rounds (solid, not hollow), and forging stock, etched in hot hydrochloric acid in accordance with ASTM A604, shall show no pipe or cracks. Porosity, segregation, inclusions, and other imperfections shall be no worse than macrographs of ASTM A604 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

3.4.1.1 Macrostructure examination is not required for bored/hollow forgings (including ring forgings) and mechanical tubing that is produced directly from ingots or large blooms (see 8.8).

3.4.1.2 If mechanical tubing is produced directly from ingots or large blooms, transverse sections may be taken from the tubing. Macroetch standards for such tubes shall be as agreed upon by the purchaser and producer (see 8.8).

3.4.2 Average Grain Size of Bars, Forgings, and Tubing

Shall be ASTM No. 5 or finer, determined in accordance with ASTM E112.

3.4.3 Hardenability of Each Heat

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 A255 except that the steel shall be normalized at 1700 °F ± 10 °F (927 °C ± 6 °C) and the specimen austenitized at 1550 °F ± 10 °F (843 °C ± 6 °C). Cast specimens do not need to be normalized.

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 the purchaser and producer.

3.4.4.3 Where 3.4.4.1 or 3.4.4.2 are not applicable, decarburization of bars shall be not greater than shown in Table 3.

Table 3A - Maximum depth of decarburization, bars, inch/pound units

Nominal Diameter or Distance Between Parallel Sides Inches	Total Depth of Decarburization Inches
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 depth of 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 the purchaser and producer.

3.4.4.4 Where 3.4.4.1 or 3.4.4.2 are not applicable, decarburization of tubing shall be not greater than shown in Table 4.

Table 4A - Maximum depth of decarburization, tubing, inch/pound units

Nominal Wall Thickness Inches	Total Depth of Decarburization Inches ID	Total Depth of Decarburization Inches 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 depth of decarburization, tubing, SI units

Nominal Wall Thickness Millimeters	Total Depth of Decarburization Millimeters 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 evaluated by one of the two methods of 3.4.4.5.1 or 3.4.4.5.2.

3.4.4.5.1 Metallographic (Microscopic) Method

A cross section of the surface shall be prepared in accordance with ASTM E1077 and examined metallographically at a magnification not to exceed 200X. The sample shall not show a layer of complete (ferrite) or partial decarburization exceeding the limits of Tables 3 and 4.

3.4.4.5.2 Hardness Traverse (Microindentation) Method

The total depth of decarburization shall be determined by a traverse method using microindentation hardness testing in accordance with ASTM E1077. Samples shall be hardened and protected during heat treatment to prevent changes in surface carbon content. Samples may be tempered at the option of the producer. Such measurements shall be far enough away from any adjacent surface to be uninfluenced by any decarburization on the adjacent surface. Acceptance shall be as listed in Tables 3 and 4.

3.4.4.5.3 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.

3.4.4.5.4 In case of dispute, the total depth of decarburization determined using the microindentation hardness traverse method shall govern.

3.4.5 Response to Heat Treatment

Extracted specimens shall meet the following requirements after being normalized by heating to 1700 °F ± 10 °F (927 °C ± 6 °C), holding at heat for not less than 1 hour, and cooling in air; hardened by heating to 1550 °F ± 10 °F (843 °C ± 6 °C), holding at heat for 1 hour ± 0.2 hour, and quenching in oil, and tempered as required to meet the properties of Tables 5 and 6 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

3.4.5.3 Unless otherwise specified, the strain rate for all tensile testing shall be set at 0.005 in/in/min (0.005 mm/mm/min) and maintained within a tolerance of ±0.002 in/in/min (±0.002 mm/mm/min) through 0.2% offset yield strain. After the yield strain, the speed of the testing machine shall be set between 0.05 in/in and 0.5 in/in (0.05 mm/mm and 0.5 mm/mm) of the length of the reduced section (or distance between the grips for specimens not having a reduced section) per minute. Alternatively, an extensometer and strain rate indicator may be used to set the strain rate between 0.05 in/in/min and 0.5 in/in/min (0.05 mm/mm/min and 0.5 mm/mm/min).

3.5 Quality

The product, as received by the 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 mechanical tubing shall be free from seams, laps, tears, and cracks after removal of the standard stock removal allowance in accordance with AS1182.

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

3.6.1 Bars

In accordance with AMS2251.

3.6.2 Mechanical Tubing

In accordance with AMS2253.

3.7 Exceptions

Any exceptions shall be authorized by the purchaser and reported as in 4.4.4.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

The producer of the product shall supply all samples for the producer's tests and shall be responsible for the performance of all required tests. The 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 (see 3.1), condition (see 3.3), macrostructure (see 3.4.1), average grain size (see 3.4.2), hardenability (see 3.4.3), decarburization (see 3.4.4), and tolerances (see 3.6) are acceptance tests and shall be performed on each heat or lot as applicable.

4.2.2 Periodic Tests

Response to heat treatment (see 3.4.5), frequency-severity cleanliness rating (see 3.5.1) and grain flow of die forgings (see 3.5.3) are periodic tests and shall be performed at a frequency selected by the producer unless frequency of testing is specified by the purchaser.

4.3 Sampling and Testing

4.3.1 Bars, Mechanical Tubing, and Forging Stock

In accordance with AMS2370.

4.3.2 Forgings

In accordance with AMS2372.

4.4 Reports

4.4.1 The producer of bar, forgings, and tubing shall furnish with each shipment a report showing the producer's identity, country where the metal was melted (e.g., final melt in the case of metal processed by multiple melting operations), the results of tests for composition, macrostructure and hardenability of each heat and for condition, and average grain size of each lot and stating that the product conforms to the other technical requirements. This report shall include the purchase order number, heat and lot numbers, AMS6411K, product form and size (and/or part number, if applicable), and quantity. If forgings are supplied, the size and melt source of stock used to make the forgings shall also be included.

4.4.2 Report the nominal metallurgically worked cross-sectional size and the cut size if different (see 3.3.1).

4.4.3 The producer of forging stock shall furnish with each shipment a report showing producer identity, country where the metal was melted (e.g., final melt in the case of metal processed by multiple melting operations) and the results of tests for composition, macrostructure, and hardenability of each heat and the results of any additional property requirements imposed by 8.8. This report shall include the purchase order number, heat number, AMS6411K, size, and quantity.

4.4.4 When material produced to this specification has exceptions taken to the technical requirements listed in Section 3 (see 5.2.1), the report shall contain a statement "This material is certified as AMS6411K(EXC) because of the following exceptions:" and the specific exceptions shall be listed.