

Steel, Bars and Forgings
3.1Cr - 11.5Ni - 13.5Co - 1.2Mo (0.21 - 0.25C)
Vacuum Melted, Normalized and Overaged
Precipitation Hardenable

(Composition similar to UNS K92580)

RATIONALE

AMS6532E results from a Five Year Review and update of this specification.

1. SCOPE

1.1 Form

This specification covers a premium aircraft-quality alloy steel in the form of bars, forgings, and forging stock.

1.2 Application

These products have been used typically for heat treated parts requiring a combination of high strength, high toughness, and weldability, but usage is not limited to such applications.

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.

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

AMS2248 Chemical Check Analysis Limits, Corrosion and Heat-Resistant Steels and Alloys, Maraging and Other Highly-Alloyed Steels, and Iron Alloys

AMS2300 Steel Cleanliness, Premium Aircraft-Quality, Magnetic Particle Inspection Procedure

AMS2310 Qualification Sampling and Testing of Steels for Transverse Tensile Properties

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SAE WEB ADDRESS:

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
AMS2750	Pyrometry
AMS2806	Identification, Bars, Wire, Mechanical Tubing, and Extrusions, Carbon and Alloy Steels and Corrosion and Heat-Resistant Steels and Alloys
AMS2808	Identification, Forgings
AS1182	Standard Stock Removal Allowance, Aircraft-Quality and Premium Aircraft-Quality Steel Bars and Mechanical Tubing

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 370	Mechanical Testing of Steel Products
ASTM A 604	Macroetch Testing of Consumable Electrode Remelted Steel Bars and Billets
ASTM E 45	Determining the Inclusion Content of Steel
ASTM E 112	Determining Average Grain Size
ASTM E 353	Chemical Analysis of Stainless, Heat-Resisting, Maraging, and Other Similar Chromium-Nickel-Iron Alloys
ASTM E 399	Plane-Strain Fracture Toughness of Metallic Materials
ASTM E 1077	Estimating the Depth of Decarburization of Steel Specimens

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

TABLE 1 - COMPOSITION

Element	min	max
Carbon	0.21	0.25
Manganese	--	0.10
Silicon	--	0.10
Phosphorus	--	0.008
Sulfur	--	0.005
Phosphorus + Sulfur	--	0.010
Chromium	2.90	3.30
Nickel	11.00	12.00
Cobalt	13.00	14.00
Molybdenum	1.10	1.30
Titanium	--	0.015
Aluminum	--	0.015
Oxygen	--	0.0020 (20 ppm)
Nitrogen	--	0.0015 (15 ppm)

3.1.1 Check Analysis

Composition variations shall meet the applicable requirements of AMS2248.

3.2 Melting Practice

Steel shall be multiple melted using vacuum induction melting followed by vacuum arc remelting.

3.3 Condition

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

3.3.1 Bars

Normalized and Overaged, having hardness not higher than 372 HB or equivalent (See 8.2), and ground or turned. Bar shall not be cut from plate.

3.3.2 Forgings

Normalized and Overaged, having hardness not higher than 372 HB or equivalent (See 8.2), and descaled.

3.3.3 Forging Stock

As ordered by the forging manufacturer.

3.4 Heat Treatment

Shall conform to the following:

3.4.1 Bars and Forgings

Shall be normalized by heating to $1650\text{ }^{\circ}\text{F} \pm 25$ ($899\text{ }^{\circ}\text{C} \pm 14$), holding at heat for 60 minutes ± 15 , and cooling in air to room temperature, and overaged by heating to $1250\text{ }^{\circ}\text{F} \pm 25$ ($677\text{ }^{\circ}\text{C} \pm 14$), holding at heat for 16 hours minimum, and air cooled. Pyrometry shall be in accordance with AMS2750.

3.4.2 Forging Stock

As ordered by the forging manufacturer.

3.5 Properties

The product shall conform to the following requirements.:

3.5.1 Macrostructure

Visual examination of transverse full cross-sections from bars, billets, and 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 shall be no worse than the macrostructure limits 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

3.5.2 Micro-Inclusion Rating of Each Heat

No specimen, shall exceed the limits shown in Table 3, determined in accordance with ASTM E 45, Method A.

TABLE 3 - MICRO-INCLUSION RATING LIMITS

Type	A	B	C	D
Thin	1.5	1.5	1.5	1.5
Thick	1.0	1.0	1.0	1.0

3.5.3 Decarburization

3.5.3.1 Bars and forging stock ordered ground or turned shall be free from decarburization on the ground or turned surfaces when determined in accordance with 3.5.3.3.

3.5.3.2 Forgings shall be supplied with a maximum decarburization of 0.040 inch (1.00 mm) when determined in accordance with 3.5.3.3, unless otherwise specified.

3.5.3.3 Decarburization shall be measured by the microscopic method per ASTM E 1077.

3.5.4 Response to Heat Treatment

3.5.4.1 Bars and Forgings

Test specimens in the Normalized and Overaged condition as specified in 3.4.1, cut from product 100 square inches (645 cm²) and under in cross-sectional area, shall meet the properties specified in 3.5.4.1.2, 3.5.4.1.3, 3.5.4.1.4, and 3.5.4.1.5 when subjected to the heat treatment in 3.5.4.1.1. Response to heat treatment verification need be performed only on the 900 °F Age (See 3.5.4.1.1.3.1), unless the purchaser specifies the 875 °F Age (See 3.5.4.1.1.3.2).

3.5.4.1.1 Precipitation Hardening Heat Treatment

3.5.4.1.1.1 Austenitization

The specimen shall be austenitized by heating to $1625\text{ °F} \pm 25$ ($885\text{ °C} \pm 14$) and holding at temperature for 60 minutes + 15/- 0 minutes and quenched using a suitable media to below 400 °F (204 °C) within 1 hour, and below 150 °F (66 °C) within 2 hours followed by air cooling or faster to room temperature.

3.5.4.1.1.2 Cold Stabilization

Within 8 hours of quenching as specified in 3.5.4.1.1.1 the specimen shall be cooled to $-100\text{ °F} \pm 15$ ($-73\text{ °C} \pm 8$) for a minimum of 1 hour. After cold stabilization, material shall be air warmed to room temperature.

3.5.4.1.1.3 Aging Treatment

After cold stabilization, the specimen shall be subject to precipitation aging as specified in either 3.5.4.1.1.3.1 or 3.5.4.1.1.3.2.

3.5.4.1.1.3.1 900 °F Age

The specimen shall be aged by heating to $900\text{ °F} \pm 10$ ($482\text{ °C} \pm 6$) for 5 to 8 hours followed by air cooling or faster. Forgings with variable section thickness may be aged at $890\text{ °F} \pm 10$ ($477\text{ °C} \pm 6$) for 5 to 8 hours in order to avoid overaging thin sections.

3.5.4.1.1.3.2 875 °F Age

The specimen shall be aged by heating to $875\text{ °F} \pm 10$ ($468\text{ °C} \pm 6$) for 5 to 8 hours followed by air cooling or faster. Forgings with variable section thickness may be aged at $865\text{ °F} \pm 10$ ($463\text{ °C} \pm 6$) for 5 to 8 hours in order to avoid overaging thin sections.

3.5.4.1.2 Tensile Properties

In accordance with ASTM A 370.

3.5.4.1.2.1 Longitudinal

Shall be as shown in Table 4; testing in the longitudinal direction need not be performed on product tested in the transverse direction.

TABLE 4 - MINIMUM LONGITUDINAL TENSILE PROPERTIES

Property	Value	Value
	Aged at 900 °F	Aged at 875 °F
Tensile Strength	280 ksi (1931 MPa)	290 ksi (1999 MPa)
Yield Strength at 0.2% Offset	235 ksi (1620 MPa)	245 ksi (1689 MPa)
Elongation in 4D	10%	10%
Reduction of Area	55%	50%

3.5.4.1.2.2 Transverse

Shall be as shown in Table 5, determined on specimens selected and prepared in accordance with AMS2310. Transverse properties apply only to product from which tensile specimens not less than 2.50 inches (63.5 mm) in length can be taken.

TABLE 5 - MINIMUM TRANSVERSE TENSILE PROPERTIES

Property	Value	Value
	Aged at 900 °F	Aged at 875 °F
Tensile Strength	280 ksi (1931 MPa)	290 ksi (1999 MPa)
Yield Strength at 0.2% Offset	235 ksi (1620 MPa)	245 ksi (1689 MPa)
Elongation in 4D	8%	8%
Reduction of Area	45%	35%

3.5.4.1.3 Hardness

Shall be not lower than 53 HRC or equivalent (See 8.2) after 900 °F Age, or not lower than 54 HRC or equivalent (See 8.2) after 875 °F Age, in accordance with ASTM A 370.

3.5.4.1.4 Fracture toughness shall meet the criteria of 3.5.4.1.4.1 using the 900 °F aging treatment or shall meet the requirements of 3.5.4.1.4.2 using the 875 °F aging treatment.

3.5.4.1.4.1 Fracture Toughness

For 900 °F Age, shall be not lower than 100 ksi $\sqrt{\text{inch}}$ (110 MPa $\sqrt{\text{m}}$) K_{IC} , determined in accordance with ASTM E 399 on specimens in the longitudinal LS or LR orientation from product 3.00 inches (76.2 mm) and over in nominal section thickness. If product size precludes use of specimens that will provide valid K_{IC} results, a K_Q value not lower than 100 ksi $\sqrt{\text{inch}}$ (110 MPa $\sqrt{\text{m}}$) will be acceptable.

3.5.4.1.4.2 Fracture Toughness

For 875 °F Age, shall be not lower than 80 ksi $\sqrt{\text{inch}}$ (88 MPa $\sqrt{\text{m}}$) K_{IC} , determined in accordance with ASTM E 399 on specimens in the longitudinal LS or LR orientation from product 3.00 inches (76.2 mm) and over in nominal section thickness. If product size precludes use of specimens that will provide valid K_{IC} results, a K_Q value not lower than 80 ksi $\sqrt{\text{inch}}$ (88 MPa $\sqrt{\text{m}}$) will be acceptable.

3.5.4.1.4.3 Invalid test results in accordance with ASTM E 399 shall be considered meaningful and the material shall be accepted to K_{IC} requirements if the thickest possible specimen was used and the calculated K_Q equals or exceeds the required K_{IC} and invalidity is due to one or both of the following conditions:

- a. $B < 2.5 (K_Q / O_t)^2$
- b. $P_{max} / P_Q > 1.10$

3.5.4.1.5 Average Grain Size

Shall be ASTM No. 8 or finer for product 100 square inches (645 cm²) and under in cross-sectional area, determined in accordance with ASTM E 112.

3.5.4.2 Forging Stock

A sample of stock shall be forged to a test coupon and heat treated as in 3.5.4.1, specimens taken from the heat treated coupon shall conform to the requirements of 3.5.4.1.2, 3.5.4.1.3, 3.5.4.1.4, and 3.5.4.1.5. Alternately specimens taken from stock after heat treatment as in 3.5.4.1 that conform to the requirements of 3.5.4.1.2, 3.5.4.1.3, 3.5.4.1.4, and 3.5.4.1.5, shall be accepted as equivalent to tests of a forged coupon.

3.6 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.

- 3.6.1 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.
- 3.6.2 Bars ordered hot rolled or cold drawn, or ground, turned, or polished shall, after removal of the standard stock removal allowance in accordance with AS1182, be free from seams, laps, tears, and cracks open to the ground, turned, or polished surface.
- 3.6.3 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.

3.7 Tolerances

Bars shall conform to all applicable requirements of AMS2251.

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

The following requirements are acceptance tests and shall be performed on each heat or lot as applicable:

- 4.2.1.1 Composition (3.1), macrostructure (3.5.1), and micro-inclusion rating (3.5.2) of each heat.
- 4.2.1.2 Hardness maximum (3.3.1) and decarburization analysis (3.5.3) of as supplied normalized and overaged product of each lot of bars and forgings
- 4.2.1.3 Tensile properties (3.5.4.1.2), hardness (3.5.4.1.3), fracture toughness (3.5.4.1.4), and average grain size (3.5.4.1.5) of each lot of bars and forgings after heat treatment using the 900 °F aging temperature as specified in 3.5.4.1.
- 4.2.1.4 Tolerances (3.7) of bars.

4.2.2 Periodic Tests

The following requirements are periodic tests and shall be performed at a frequency selected by the vendor unless frequency of testing is specified by purchaser:

- 4.2.2.1 Tensile properties (3.5.4.1.2), hardness (3.5.4.1.3), and fracture toughness (3.5.4.1.4), and average grain size (3.5.4.1.5) of each lot of bars or forgings after heat treatment using the 875 °F aging temperature as specified in 3.5.4.1.
- 4.2.2.2 Ability of forging stock to develop required properties (3.5.4.2).