



AEROSPACE MATERIAL Society of Automotive Engineers, Inc. SPECIFICATION

400 COMMONWEALTH DRIVE, WARRENDALE, PA. 15096

AMS 2376

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Revised

QUALIFICATION, APPROVAL, AND CONTROL OF PREMIUM-QUALITY FORGINGS Alloy Steels and Heat-Treatable Corrosion and Heat Resistant Steels and Alloys

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1. SCOPE:

- 1.1 **Purpose:** This specification covers the procedures for approval of premium-quality forgings, usually serialized, and of the stock from which such forgings are produced, and the controls to be exercised in producing the forgings and forging stock.
- 1.2 **Application:** Primarily for highly-stressed parts produced from forgings which require approval of the forgings and the stock from which they are made and facets of their production to ensure that production lots of forgings are of the same metallurgical quality and are produced by the same basic procedures as the forgings and stock originally qualified. Applicable to parts made of alloy steels and heat-treatable corrosion and heat resistant steels and alloys and which are subjected to rigid inspection standards throughout manufacture from ingot to finished part.
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) 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., 400 Commonwealth Drive, Warrendale, PA 15096.
 - 2.1.1 **Aerospace Material Specifications:**
 - AMS 2300 - Premium Aircraft-Quality Steel Cleanliness, Magnetic Particle Inspection Procedure
 - AMS 2350 - Standards and Test Methods
 - AMS 2630 - Ultrasonic Inspection
 - AMS 2760 - Heat Treatment, Carbon, Low-Alloy, and Specialty Steels
 - 2.2 **ASTM Publications:** Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.
 - ASTM A604 - Macroetch Testing of Consumable Electrode Vacuum-Arc Remelted Steel Bars and Billets
 - 2.3 **Government Publications:** Available from Commanding Officer, Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120.
 - 2.3.1 **Military Standards:**
 - MIL-STD-163 - Steel Mill Products, Preparation for Shipment and Storage
3. **TECHNICAL REQUIREMENTS:**
 - 3.1 **Ingot:** Shall be produced, by a source approved by purchaser of the forgings, under effective, documented controls of all variables of the melting processes to produce, consistently, uniform ingots which will yield products meeting the requirements of this specification, the applicable material specification, and applicable drawings.

3.1.1 **Melting Practice:** Shall be as specified in the applicable material specification; if not specified therein, steel or alloy shall be multiple melted using either vacuum arc consumable electrode or electroslag practice in the remelt cycle.

3.1.2 **Ingot Molds:** Shall be metallurgically clean and free of foreign materials. Molds into which steel or alloy is cast shall not have been previously used in casting ingots of leaded or free-machining steels.

3.1.3 **Identification:** Each ingot shall be marked with the mill heat number and pouring sequence in such a manner that the top and/or bottom is traceable.

3.2 **Forging Stock:** Billets, bars, slabs, and tubes for forging shall be manufactured from ingot produced as in 3.1 and shall be procured only from sources approved by purchaser of the forgings. Parameters shall be established for ingot conversion procedures which will produce stock conforming to the requirements of 3.2.1, 3.2.2, 3.2.3, and 3.2.4. These parameters shall be monitored and recorded on a continuous or periodic basis, as agreed upon by purchaser and vendor. Deviations from established control factors (See 4.4.2.1.1) shall be reported to the purchaser of the stock and his approval obtained before the stock may be considered acceptable.

3.2.1 **Macrostructure:** Visual examination of transverse sections of billets, bars, slabs, and tubes or tube rounds, etched in accordance with ASTM A604 in hot hydrochloric acid (1:1) at 160° - 180°F (71° - 82°C), or in other suitable etchant at a temperature appropriate for the alloy, for sufficient time to develop a well-defined macrostructure, shall show no imperfections, such as pipe, cracks, porosity, laps, folds, segregation, and inclusions, detrimental to usage of the product. Except as specified in 3.2.1.1, macrostructure shall be equal to or better than the following macrographs in ASTM A604 unless other limits are established in the applicable material specification:

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

3.2.1.1 When tubes are produced directly from ingots or large blooms, specimens for macrostructure testing may be taken from tubes rather than tube rounds. Macrostructure standards for such tubes shall be as agreed upon by purchaser and vendor.

3.2.2 **Magnetic Particle Cleanliness:** Alloy steels and ferromagnetic corrosion resistant steels shall meet the requirements of AMS 2300.

3.2.3 **Ultrasonic Soundness:** Shall meet the standards specified by the purchaser determined in accordance with AMS 2630.

3.2.4 **Heat Identification:** Each bar, billet, bloom, and tube shall be marked with the mill heat number and ingot number. In addition, each bar, billet, bloom, and tube 4.0 in. (102 mm) and over in nominal diameter or distance between parallel sides shall be marked to show the quarter position in the ingot, or as specified by purchaser of the forgings.

3.2.5 The forging vendor shall determine that the stock conforms to the applicable material specification and will yield acceptable forgings except that tests which are characteristic of a heat and which are conducted by the forging stock vendor need not be repeated by the forging vendor. Vendor shall also determine that the stock is from an approved mill source.

3.2.5.1 The forging vendor shall obtain complete test reports from the mill on each heat of forging stock; the reported results shall be verified in conjunction with quality conformance testing.

3.3 Forgings: Shall be produced from stock conforming to 3.2. Forgings shall be formed to their final rough dimensions by one or a combination of the following processes, unless a particular process is specified:

Hammer die
Press die
Hot upset
Ring roll
Mandrel forge
Extrusion

3.3.1 Preproduction Forgings:

3.3.1.1 Vendor shall establish the forging sequence and other processing procedures, such as heat treating and cleaning, suitable for producing premium-quality forgings. These procedures shall be documented on operation sheets for the purpose of maintaining consistent practices. The operation sheets shall be submitted to the purchaser for approval.

3.3.1.2 Vendor shall produce one or more preproduction forgings and shall heat treat and test a forging or sections thereof to all requirements of the material specification, the drawing, and any additional requirements specified by the purchaser. The preproduction forgings shall be produced by the practices to be used on production forgings in accordance with the approved operation sheets and, unless otherwise specified, may be produced as part of the initial production run. A duplicate preproduction forging or the remaining section of such a forging shall be submitted to the purchaser for confirmatory testing.

3.3.1.3 The location(s) from which coupons for mechanical tests are taken and the sections for grain flow examination shall be as specified by the purchaser. The vendor shall perform the required tests on specimens from these locations. If no locations are specified, vendor shall select representative areas for testing, subject to concurrence of the purchaser.

3.3.1.4 Flow Pattern Control: Forging stock shall be of such size and dimensions that the work accomplished in forming to finished shape shall result in approximately uniform grain size throughout the forging. The techniques employed shall produce a grain flow pattern conforming to the structural shape of the part and essentially free from both reentrant and sharply-folded flow lines.

3.3.1.4.1 A forging shall be sectioned through areas indicated by the purchaser and the sections suitably etched to show the grain flow. Photographs showing the grain flow shall be made of each section and the photographs shall be identified so as to be related to the corresponding sections in the forging. The grain flow shall conform to the requirements specified by the purchaser and to good forging practice consistent with the shape of the forging.

3.3.1.5 Heat Treatment: The forging(s) shall be heat treated by the forging vendor, or by a heat treatment source approved by purchaser of the forgings, to the final condition of the part. If the as-forged section size is too large to achieve proper heat treatment response, the forging vendor shall, prior to heat treatment, machine the forging(s) to a configuration essentially that in which production forgings will be heat treated or machine sections from the forging(s) to simulate the maximum section size in the finished forging. Heat treatment of alloy steels shall be performed in accordance with AMS 2760. Heat treatment of corrosion and heat resistant steels and alloys shall be performed in equipment meeting the requirements of, and under the controls specified in, AMS 2760, using the temperatures, times, and heating and cooling media specified in the applicable material specification, on the drawing, or in the purchaser's process specification.

3.3.1.6 **Mechanical Properties:** Test specimens from the representative forging(s) or forging sections shall meet the mechanical properties for the part in the final heat treated condition as specified in the applicable material specification or on the drawing. Variations from specified properties, because of section size or test specimen orientation, shall be as agreed upon by purchaser and vendor.

3.3.1.7 **Hardness:** Hardness surveys shall be made across the heaviest sections through a test forging or forging section in the final heat treated condition, unless otherwise specified. The sections prepared as in 3.3.1.4.1 may be used for the survey if they meet the criteria of 3.3.1.5 for forging sections.

3.3.1.8 **Microstructure:** Specimens shall be taken from the fully heat treated forging at the center of the heaviest section and at the surface of the heaviest and thinnest sections and prepared for metallographic examination. The structure shall be essentially uniform and free from defects and from indications of overheating and burning. Photographs of the microstructures shall be submitted to the purchaser and any abnormal microstructural conditions identified. These photographs may be used to establish standards for production forgings.

3.3.2 **Control Factors:** A resume of the control factors (See 4.4.2.1) established for producing forgings of each part number shall be submitted with the results of tests on the preproduction forging(s); when permitted by purchaser, the resume need not be submitted with the test results but shall be kept on file for review by the purchaser.

3.3.3 **Production Forgings:** Shall be produced using the same operations, practices, and control factors used on the approved preproduction forgings.

3.3.3.1 Production forgings shall not be shipped until the vendor has received from the purchaser written approval of the preproduction forging(s), and the processing, unless preshipment approval be waived by purchaser.

4. QUALITY ASSURANCE PROVISIONS:

4.1 **Responsibility for Inspection:** The forging vendor 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 4.7. Purchaser reserves the right to perform such confirmatory testing as he deems necessary to ensure that the forgings conform to the requirements of this specification.

4.2 **Classification of Tests:**

4.2.1 **Acceptance Tests:** Tests of forging stock and production forgings to determine conformance to the applicable material specification and to any additional requirements specified by the purchaser are classified as acceptance tests.

4.2.2 **Qualification Tests:** Tests of preproduction forgings to determine conformance to all technical requirements of the applicable material specification, to 3.3.1 of this specification, and to any additional requirements specified by the purchaser are classified as qualification tests.

4.2.2.1 For direct U.S. Military procurement of forgings, substantiating test data and qualification test forgings shall be submitted to the cognizant qualification agency as directed by the procuring activity, the contracting officer, or the request for procurement.

4.3 **Sampling:** Shall be as follows; a lot shall be all forgings of the same part number or configuration, opposite hands being considered one configuration, produced from the same heat of forging stock, heated and forged in the same manner, and heat treated in a continuous furnace or in a series of batch-type furnace operations with no change in furnace settings or interruption of power.

4.3.1 Acceptance Tests: As specified in the material specification and as follows:

- 4.3.1.1 Mechanical properties shall be determined on each forging or on a prolongation of each forging furnished heat treated to the final condition of the part when serialization of forgings is required, unless otherwise specified.
- 4.3.1.2 Samples shall be taken from the first shipment of forging stock of each heat to determine ability of stock from that heat to yield acceptable forgings and to meet all acceptance test and periodic test requirements of the material specification.
- 4.3.2 Qualification Tests: As specified in Section 3; tests shall be conducted at the time of the first production of a new forging by a vendor and following any change in configuration of the forging design.
- 4.3.3 Mechanical Property Test Specimens: Shall be taken in the locations and directions specified by the purchaser.

4.4 Approval:

- 4.4.1 Preproduction forgings and the forging procedure shall be approved by purchaser before forgings for production use are supplied. Approval of preproduction forgings shall in no way relieve the forging vendor of responsibility for continued conformance to all purchase order requirements.
- 4.4.2 The respective vendors shall establish for forging stock and for forgings of each part number or configuration the parameters for the control factors of processing which will yield products meeting the respective requirements of this specification and the applicable material specification. These shall constitute the approved manufacturing procedures for each product and shall be used for subsequent production of the product. If any change is necessary in control factors of processing, vendor shall submit for reapproval a statement of the proposed changes in processing and, when requested, sample product. Production products made by the revised procedure shall not be shipped prior to receipt of reapproval.

4.4.2.1 Control factors for producing the respective products include, but are not limited to, the following:

4.4.2.1.1 Forging Stock:

Type of furnace for each melt cycle
Source and size of ingot from final melt cycle
Ingot cooling procedure after final melt cycle
Ingot quality analysis procedure
Conversion source if not the ingot source
Preparation of ingot for conversion
Ingot heating procedure
Cogging and rolling procedures
Inspection procedures

4.4.2.1.2 Forgings:

Source of forging stock

Type (ingot, bloom, billet, bar, tube), nominal size (cross-sectional area), shape, and multiple-weight of forging stock

Type of forging equipment (press, hammer, ring roll, etc, See 3.3)

Parting line location

Sequence and number of operations, changes in which would result in a different cross-sectional structure, grain flow, or working of the metal

Protective atmosphere or coatings, or both

Thermal cycling, including preheating temperature, forging temperature range, and heat treatment temperatures, times, and methods of cooling

Cleaning operations (e.g., chemical descaling, abrasive blasting, etc)

Inspection procedures

4.4.2.1.3 Any of the above control factors of processing considered proprietary by the vendor may be assigned a code designation. Each variation in such factors shall be assigned a modified code designation.

4.5 Documentation:

4.5.1 Maintenance of Facilities: Each vendor shall keep records demonstrating that the facilities used to produce, control, measure, and test forging stock and forgings during manufacture and inspection are properly maintained and are checked for accuracy at stated intervals against recognized standards.

4.5.2 Process Sheets: Each vendor shall prepare and maintain documented instructions defining the processing methods and routing in the manufacturing cycle for producing the respective products. Separate process sheets shall be prepared and maintained for each forging configuration, opposite hands being considered a single-configuration.

4.5.3 Traceability: When serialization of forgings is required, the vendor shall maintain records to provide traceability of the forging to its location in the final remelt ingot to the extent specified in 3.2.4, or other requirements. Records shall be maintained for at least seven years or as specified by purchaser.

4.5.3.1 Records shall account for all forging multiples cut from each heat and for those portions of a heat which were unacceptable, detailing the reasons for rejection.

4.5.4 Heat Treatment:

4.5.4.1 When serialization of forgings is required, a furnace loading diagram shall, when required by purchaser of the forgings, be established for the purpose of maintaining traceability of any specific forging furnished in the final condition of the part to its particular heat treatment batch and position in the furnace. Each heat treated forging shall be represented on the furnace loading diagram with the identification assigned in 4.5.3 and 5.1.2.

4.5.4.2 When the heat treated condition of certain air-hardening steels and of precipitation-hardenable steels and alloys cannot be distinguished by hardness, the vendor shall mark each forging after each individual heat treatment operation to indicate that the operation was completed.

4.5.4.3 The vendor shall keep records of all furnace charts for each heat treatment batch or cycle. Information retained shall include the temperature, time, and furnace loading diagram. The records shall be kept on file for not less than seven years, unless otherwise agreed upon by purchaser and vendor.