

# AEROSPACE MATERIAL SPECIFICATION

**SAE** MAM 2304A

Issued JUL 1991  
Revised JUN 2001

Superseding MAM 2304

## Steel Cleanliness, Special Aircraft-Quality Magnetic Particle Inspection Procedure Metric (SI) Measurement

### 1. SCOPE:

#### 1.1 Purpose:

This specification covers steel cleanliness requirements in metric SI units for special aircraft-quality ferromagnetic steels, other than hardenable corrosion resistant steels, by magnetic particle inspection methods.

1.1.1 AMS 2304 is the inch/pound version of this MAM.

#### 1.2 Application:

This procedure has been used typically for the cleanliness evaluation of blooms, billets, tube rounds, stock for forging or flash welded rings, slabs, bars, sheet, plate, tubing, and extrusions used in fabricating highly stressed parts where very strict magnetic particle inspection standards are used in final inspection of such parts, but may be used for qualification of a heat, melt or lot of steel.

1.2.1 Product qualified to this specification is not recommended for use in parts where the high transverse properties of vacuum-arc-remelted or electroslag remelted steels are required (See 8.2).

### 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 canceled and no superseding document has been specified, the last published issue of that document shall apply.

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## 2.1 ASTM Publications:

Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM E 10 Brinell Hardness of Metallic Materials  
ASTM E 1444 Magnetic Particle Examination

## 2.2 ANSI Publications:

Available from American National Standards Institute, Inc., 11 West 42nd Street, New York, NY 10036-8002.

ANSI B46.1 Surface Texture

## 3. TECHNICAL REQUIREMENTS:

### 3.1 Specimen Preparation:

3.1.1 Heat Qualification: Sampling shall be in accordance with 4.3.1. Samples shall be converted into test specimens in accordance with 3.1.3.

3.1.2 Product Qualification: Product from a heat not qualified based on sampling as in 4.3.1 shall be sampled in accordance with 4.3.2. Samples shall be converted into test specimens in accordance with 3.1.3.

### 3.1.3 Working and Rough Machining:

3.1.3.1 Solid Product 300 mm and Over in Nominal Diameter or Distance Between Parallel Sides: A quarter section shall be cut from the sample sufficiently oversize that the center of the original sample will be approximately on the surface of the specimen after generating to test size. The quartered section shall then be forged to a 75 to 150 mm round or square, maintaining the axis of the forging approximately parallel to the original direction of rolling. As an alternate method, the full section may be rolled or forged to a 150 mm round or square and an oversize quarter obtained as in 3.1.3.3. Specimens shall be rough machined to a "one-step" straight cylinder nominally 125 mm long. Minimum stock removal shall be consistent with the machining allowance specified in 3.1.4.1.

3.1.3.2 Solid Product Over 150 to 300 mm, Exclusive, in Nominal Diameter or Distance Between Parallel Sides Except Slabs and Plates: A quarter section shall be cut from each sample sufficiently oversize that the center of the original sample will be approximately on the surface of the specimen after generating to test size. The quarter section shall be converted into a test specimen by machining, or forging and machining, to a 75 to 150 mm round or square. Specimens shall be rough machined to a "one-step" straight cylinder nominally 125 mm long. Minimum stock removal shall be consistent with the machining allowance specified in 3.1.4.1.

3.1.3.3 Solid Product 150 mm and Under in Nominal Diameter or Distance or Distance Between Parallel Sides Except Flat Bars, Slabs, and Plates: A quarter section shall be cut from each sample sufficiently oversize that the center of the original sample will be approximately on the surface of the specimen after generating to test size. The quarter section shall be converted into a test specimen by machining to a "one-step" straight cylinder nominally 125 mm long. Minimum stock removal shall be consistent with the machining allowance specified in 3.1.4.1.

3.1.3.3.1 As an alternate method, a stepdown specimen may be generated from the full cross-section in equal length circumferential steps as shown in Table 1.

TABLE 1 - Stepdown Specimens - Cylindrical

| Nominal Diameter or Distance Between Parallel Sides Millimeters | Step Length Millimeters | Step Diameter 1 | Step Diameter 2 | Step Diameter 3 | Step Diameter 4 | Step Diameter 5 |
|---|-------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 6.25 to 12.50, incl   | 125.00                  | D               | --              | --              | --              | --              |
| Over 12.5 to 18.75, incl  | 62.50                   | D               | 2/3D            | --              | --              | --              |
| Over 18.75 to 25.00, incl                                       | 41.62                   | D               | 3/4D            | 1/2D            | --              | --              |
| Over 25.00 to 37.50, incl                                       | 31.25                   | D               | 4/5D            | 3/5D            | 2/5D            | --              |
| Over 37.50  | 25.00                   | D               | 4/5D            | 3/5D            | 2/5D            | 1/5D            |

D = Original diameter or distance between parallel sides minus machining stock removed.

3.1.3.4 Flat Bars: Specimens nominally 125 mm long shall be rough machined to equal-length steps across the width of the specimen, in accordance with Table 2, allowing 20% of the thickness or 2.50 mm, whichever is less, for minimum stock removal. Allowance of 0.25 mm shall be made for finish machining.

TABLE 2 - Stepdown Specimens - Flat Bars

| Nominal Thickness Millimeters | Step Length Millimeters | Step Thickness 1 | Step Thickness 2 | Step Thickness 3 | Step Thickness 4 | Step Thickness 5 |
|-------------------------------|-------------------------|------------------|------------------|------------------|------------------|------------------|
| Up to 6.25, incl              | 125.00                  | T                | --               | --               | --               | --               |
| Over 6.25 to 12.50, incl      | 62.50                   | T                | 2/3T             | --               | --               | --               |
| Over 12.50 to 25.00, incl     | 31.25                   | T                | 3/4T             | 1/2T             | 1/4T             | --               |
| Over 25.00                    | 25.00                   | T                | 4/5T             | 3/5T             | 2/5T             | 1/5T             |

T = Original nominal thickness minus machining stock removed.

- 3.1.3.5 Slabs or Plates: A straight cylindrical or rectangular specimen shall be machined, or forged and machined, from each slab or plate to be tested. The specimen shall be taken essentially parallel to the direction of rolling at the center of the slab or plate width and thickness and shall be nominally 125 mm in length, and not more than 100 mm in final diameter or thickness.
- 3.1.3.5.1 Product Up to 100 mm, Inclusive, in Nominal Thickness: A straight cylindrical specimen shall represent the full thickness consistent with the machining allowance specified in 3.1.4.1.
- 3.1.3.5.2 Product Over 100 to 200 mm, Inclusive, in Nominal Thickness: A straight cylindrical specimen shall represent surface to mid-thickness consistent with the machining allowance specified in 3.1.4.1.
- 3.1.3.5.3 Product Over 200 mm in Nominal Thickness: A straight cylindrical specimen shall be taken so that the axis is approximately midway between the surface and mid-thickness, and shall have a diameter equal to one-third the nominal thickness of the section.
- 3.1.3.6 Tubing:
- 3.1.3.6.1 Nominal Wall Thickness 6.25 mm and Over: Specimens, nominally 125 mm long, shall be rough machined to four equal circumferential steps, T, 3/4T, 1/2T, and 1/4T, allowing 2.50 mm on the diameter for stock removal. Allowance of 0.25 mm on the radii for finish machining shall be made. T = nominal wall thickness minus the machining allowance.
- 3.1.3.6.2 Nominal Wall Thickness Under 6.25 mm: Specimens, nominally 125 mm long, after heat treatment as in 3.1.5, shall have 10% of the wall thickness or 0.38 mm, whichever is less, removed from the outer diameter and be tested as a straight cylinder.
- 3.1.4 Machining:
- 3.1.4.1 Product Other Than Flat Bars, Slabs, and Plates Over 8 Inches Thick, and Tubing: The converted sample shall be machined to conform to the allowance of Table 3 for surface removal, allowing 0.25 mm per side for finish machining after heat treatment.

TABLE 3 - Stock Removal

| Nominal<br>Diameter or Distance<br>Between Parallel Sides<br>Millimeters | Minimum<br>Stock Removal<br>Millimeters per Side |
|--|--|
| 6.25 to 12.50, incl  | 0.75   |
| Over 12.50 to 18.75, incl  | 1.15   |
| Over 18.75 to 25.00, incl  | 1.50   |
| Over 25.00 to 37.50, incl  | 1.90   |
| Over 37.50 to 50.00, incl  | 2.25   |
| Over 50.00 to 62.50, incl  | 3.20   |
| Over 62.50 to 87.50, incl  | 4.00   |
| Over 87.50 to 112.50, incl   | 4.75   |
| Over 112.50 to 150.00, incl  | 6.25   |

3.1.5 Heat Treatment: Rough machined specimens shall, if necessary, be heat treated by suitably austenitizing, quenching, and tempering or by solution and precipitation heat treating to produce hardness of 248 to 352 HB or appropriate lower hardness for steel of low hardenability. Hardness testing shall be in accordance with ASTM E10. Specimens shall be austenitized in a neutral or slightly reducing atmosphere. Following heat treatment, surface scale may be removed by grit blasting or other acceptable method.

3.1.6 Finish Machining: The heat treated specimens shall be finish machined to surface roughness not greater than 0.8 micrometers AA, determined in accordance with ANSI B46.1. The ends of the specimen shall be finished to provide good electrical contact.

### 3.2 Inspection:

Magnetic particle inspection shall be performed in accordance with ASTM E 1444 by the circular, wet, continuous method (See 8.5) using 32 to 48 A/mm of diameter. If a stepdown bar is used, the smallest step shall be magnetized and inspected first; the larger steps shall be magnetized and inspected individually in succession of increasing size until all steps have been evaluated. If a longitudinal slice from slab or plate, as in 3.1.3.5, is used, only the longitudinal surfaces perpendicular to the two faces of the slab or plate shall be inspected.

3.2.1 Cleanliness standards presented herein govern nonmetallic inclusions only (See 8.5). Steel which, during inspection, reveals indications representing actual ruptures, such as cracks, seams, laminations, and laps, shall be subject to rejection except where these anomalies result from sample preparation.

3.2.2 The results of the magnetic particle inspection shall be appropriately recorded. All recorded results shall be identified, filed, and made available to purchaser upon request.

### 3.3 Evaluation of Steel Cleanliness:

After inspection, each indication 0.4 mm and over shall be recorded on an inspection chart. All recorded results shall be identified, filed, and, upon request, made available to purchaser. Records shall be available for at least three years after shipment of the product. The frequency (F) number and the severity (S) length of the indications shall be calculated as follows:

#### 3.3.1 Frequency (F):

3.3.1.1 The number of indications per test specimen is totaled.

3.3.1.2 The frequency per specimen is determined by dividing 6.45 times the total number of indications for each specimen by the test surface area of the specimen in square centimeters.

3.3.1.3 The frequency ratings for all test specimens from a heat are totaled.

3.3.1.4 The average frequency rating (F) equals the total frequency rating for all test specimens from a heat divided by the number of test specimens.

#### 3.3.2 Severity (S):

3.3.2.1 The length of each indication is recorded.

3.3.2.2 The product for each specimen is computed by totaling the product of the number of indications times the appropriate progression factor shown in Table 4.

TABLE 4 - Progression Factor for Severity Rating

| Length of Indication<br>Millimeters | Progression Factor |
|-------------------------------------|--------------------|
| 0.4 to 0.8, excl                    | 13                 |
| 0.8 to 1.6, excl                    | 26                 |
| 1.6 to 3.2, excl                    | 103                |
| 3.2 and over                        | 1650               |

3.3.2.3 The severity per specimen is determined by dividing the product for each specimen by the test surface area of the specimen in square centimeters.

3.3.2.4 The severity ratings for all test specimens from a heat are totaled.

3.3.2.5 The average severity rating (S) equals the total severity rating for all test specimens from a heat divided by the number of test specimens.

#### 3.4 Disposition:

Product inspected in accordance with this specification shall conform to the following requirements as applicable:

3.4.1 Product inspected for heat qualification as in 4.3.1 and for product qualification as in 4.3.2 shall conform to a maximum average frequency rating (F) of 0.25 and a maximum average severity rating (S) of 0.50.

3.4.2 Product inspected in accordance with this specification and having frequency-severity rating exceeding the specified limits may be reevaluated for specific applications when permitted by purchaser. Evaluation of any one or two steps of stepdown specimens may be waived by purchaser when the area represented is not considered critical for the end product.

#### 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:

All applicable technical requirements are acceptance tests and shall be performed as specified in 4.2.1 or 4.2.2.

4.2.1 Heat Qualification: Tests of samples taken as in 4.3.1 to determine conformance to heat qualification requirements, if acceptable, need be conducted only once per heat.

4.2.1.1 Heats which have been qualified as semi-finished product shall be considered qualified for finished product.

4.2.2 Product Qualification: Tests on product not "heat qualified" shall be conducted on product of each size and shape of each lot made from each heat.

##### 4.3 Sampling and Testing:

The sampling procedure for heat qualification described in 4.3.1 shall be performed by the producer. No further sampling by the producer shall be required from a heat which meets the requirements of 3.4.1. Sampling procedure on the product shall be as described in 4.3.2.

#### 4.3.1 Heat Qualification:

4.3.1.1 Heats of Top-Poured Ingots: Samples shall be taken from semi-finished or finished product representing the top and bottom of the first ingot and last usable ingot from heats having not more than 10 ingots, or not over 27,300 kilograms, or from portions of heats within these limits; and from the top and bottom of the first, middle, and last usable ingot of heats having more than 10 ingots or over 27,200 kilograms.

4.3.1.2 Heats of Bottom-Poured Ingots: Samples shall be taken from semi-finished or finished product representing the top and bottom of three ingots. One ingot shall be taken at random from the first usable plate poured, one ingot at random from the usable plate poured nearest to the middle of the heat, and one ingot at random from the last usable plate poured. When a heat consists of two usable plates, two of the sample ingots shall be selected from the second usable plate poured. When a heat consists of a single usable plate, any three random ingots may be selected.

4.3.1.2.1 If there are less than three ingots in the heat, samples shall be taken representing the top and bottom of all ingots.

4.3.1.3 Strand-Cast Heats: Samples shall be taken from semi-finished or finished product having at least a 3:1 reduction in cross-section from the cast strand, or samples of the as-cast strand similarly reduced, representing the front, middle, and back of both strands when two strands are cast, or of an inside strand and an outside strand when more than two strands are cast. When a single strand is cast, six samples having at least a 3:1 reduction from the cast strand, or samples of the cast strand similarly reduced, representing both ends of the first, middle, and last usable cuts (blooms) of the strand or product shall be taken.

4.3.2 Product Qualification: Samples shall be taken at random from not less than 10% of the pieces of each lot. A lot shall be all product of one size from one heat in one shipment. Not less than three nor more than ten samples shall be selected from a lot, except that if the quantity in the lot is three pieces or less, one sample shall be taken from each piece.

#### 4.4 Reports:

The vendor of the product shall include the MAM 2304A frequency-severity rating for each lot in the shipment, in addition to other information required by the applicable material specification.

#### 4.5 Resampling and Retesting:

4.5.1 Product Other Than Slabs and Plates: If any specimen used in the above tests fails to meet the specified requirements, disposition of the heat or lot may be based on the results of testing three additional specimens for each original nonconforming specimen; additional specimens shall be as follows:

- 4.5.1.1 Heats of Top-Poured Ingots: One of the additional specimens shall be taken from the same position from product from each of the two available ingots most immediately adjacent in pouring sequence to that from which the originally nonconforming specimen was taken. The third specimen shall be taken from product of the original nonconforming ingot after additional discard. Should the latter specimen be unacceptable, resampling and retesting of the nonconforming ingot may be repeated after as many consecutive discards as necessary to obtain acceptable results. Should any of the adjacent ingot tests fail to meet the specified requirements, resampling and retesting of these ingots will be permitted using the procedure specified for the original nonconforming ingot.
- 4.5.1.2 Heats of Bottom-Poured Ingots: One of the additional specimens shall be taken from the same position from product from each of the two available ingots most immediately adjacent to that from which the originally nonconforming specimen was taken. The third specimen shall be taken from product of the original nonconforming ingot after additional discard. Should the latter specimen be unacceptable, resampling and retesting of the nonconforming ingot may be repeated after as many consecutive discards as necessary to obtain acceptable results. Should any of the adjacent ingot tests fail to meet the specified requirements, resampling and retesting of those ingots will be permitted using the procedure specified for the original nonconforming ingot.
- 4.5.1.2.1 If there are less than three ingots in the heat, all test locations that fail shall be retested after discard is taken.
- 4.5.1.3 Strand Cast Heats: One of the additional samples shall be taken from the section adjacent to the original nonconforming specimen after sufficient discard, and the two adjacent cuts (blooms) shall be sampled at both ends and tested. Should any of the adjacent cut (bloom) test locations fail to meet the specified requirements, resampling and retesting of those locations will be permitted using the procedure specified for the original nonconforming location.
- 4.5.2 Slab and Plate:
- 4.5.2.1 For Heat Qualification: If the average of the specimens from a heat fails to meet the requirements of 3.4 for the average of all original specimens, disposition of the heat may be based on the results of testing three additional specimens for each original specimen to be retested. Two of the additional specimens shall be taken so as to be representative of the heat. The third specimen shall be taken from the original nonconforming slab or plate after additional discard. Should the average of the results on the original specimens not requiring retesting plus those on the additional specimens fail to meet the requirements of 3.4, resampling and retesting may be repeated after as many discards as necessary to obtain acceptable results.

4.5.2.2 For Product Qualification: If the average of all specimens from slabs or plates from a heat fails to meet the requirements of 3.4, or if the average of all specimens from a lot of plate not qualified as a heat fails to meet the requirements of 3.4, disposition of the product may be based on the results of testing three specimens for each original specimen which exceeds the average frequency or severity limit, or both, of 3.4. The retest specimens shall be taken so as to be representative of the heat or lot. Should the average of the results on the original specimens not requiring retesting plus those on the retest specimens fail to meet the requirements of 3.4, resampling and retesting may be repeated after as many discards as necessary to obtain acceptable results.

## 5. PREPARATION FOR DELIVERY:

### 5.1 Identification:

Steel accepted for use in accordance with this specification shall be identified with MAM 2304A in addition to information required by the applicable material specification.

## 6. ACKNOWLEDGMENT:

A vendor shall mention this specification number and its revision letter in all quotations and when acknowledging purchase orders.

## 7. REJECTIONS:

Steel not conforming to this specification, or to modifications authorized by purchaser, will be subject to rejection.

## 8. NOTES:

8.1 A change bar ( I ) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this specification. An (R) symbol to the left of the document title indicates a complete revision of the specification, including technical revisions. Change bars and (R) are not used in original publications, nor in specifications that contain editorial changes only.

### 8.2 Melting Practice:

Steel supplied to this specification may be single melted in air and either static or continuous cast. Although it is required to meet the same cleanliness limits as consumable electrode melted steel, it should not be considered equivalent.