



Designation: E 45 – 97 (Reapproved 2002)

## Standard Test Methods for Determining the Inclusion Content of Steel<sup>1</sup>

This standard is issued under the fixed designation E 45; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the Department of Defense.*

### 1. Scope

1.1 These test methods cover a number of recognized methods for determining the nonmetallic inclusion content of wrought steel. Macroscopical methods include macroetch, fracture, step-down, and magnetic particle tests. Microscopical methods include five generally accepted systems of examination. In these microscopical methods, inclusions are assigned to a category based on similarities in morphology, and not necessarily on their chemical identity. Metallographic techniques that allow simple differentiation between morphologically similar inclusions are briefly discussed. While the methods are primarily intended for rating inclusions, constituents such as carbides, nitrides, carbonitrides, borides, and intermetallic phases may be rated using some of the microscopical methods. In some cases, alloys other than steels may be rated using one or more of these methods; the methods will be described in terms of their use on steels.

1.2 These test methods are suitable for manual rating of inclusion content. Other ASTM standards cover automatic methods for obtaining JK ratings (Practice E 1122) and inclusion content using image analysis (Practice E 1245).

1.3 Depending on the type of steel and the properties required, either a macroscopical or a microscopical method for determining the inclusion content, or combinations of the two methods, may be found most satisfactory.

1.4 These test methods deal only with recommended test methods and nothing in them should be construed as defining or establishing limits of acceptability for any grade of steel.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

### 2. Referenced Documents

#### 2.1 ASTM Standards:

<sup>1</sup> This practice is under the jurisdiction of ASTM Committee E04 on Metallography and is the direct responsibility of Subcommittee E04.09 on Inclusions.

Current edition approved Apr. 10, 1997. Published June 1997. Originally published as E 45 – 42 T. Last previous edition E 45 – 97<sup>ε2</sup>.

- A 295 Specification for High-Carbon Anti-Friction Bearing Steel<sup>2</sup>
- A 485 Specification for High Hardenability Anti-Friction Bearing Steel<sup>2</sup>
- A 534 Specification for Carburizing Steels for Anti-Friction Bearings<sup>2</sup>
- A 535 Specification for Special-Quality Ball and Roller Bearing Steel<sup>2</sup>
- A 756 Specification for Stainless Anti-Friction Bearing Steel<sup>2</sup>
- A 866 Specification for Medium Carbon for Anti-Friction Bearing Steel<sup>2</sup>
- D 96 Test Method for Water and Sediment in Crude Oil by Centrifuge Method (Field Procedure)<sup>3</sup>
- E 3 Guide for Preparation of Metallographic Specimens<sup>4</sup>
- E 7 Terminology Relating to Metallography<sup>4</sup>
- E 381 Method of Macroetch Testing Steel Bars, Billets, Blooms, and Forgings<sup>4</sup>
- E 709 Guide for Magnetic Particle Examination<sup>5</sup>
- E 768 Practice for Preparing and Evaluating Specimens for Automatic Inclusion Assessment of Steel<sup>4</sup>
- E 1122 Practice for Obtaining JK Inclusion Ratings Using Automatic Image Analysis<sup>4</sup>
- E 1245 Practice for Determining Inclusion or Second-Phase Constituent Content of Metals by Automatic Image Analysis<sup>4</sup>
- 2.2 *SAE Standards:*<sup>6</sup>
  - J421, Cleanliness Rating of Steels by the Magnetic Particle Method
  - J422, Recommended Practice for Determination of Inclusions in Steel
- 2.3 *Aerospace Material Specifications:*
  - 2300, Premium Aircraft-Quality Steel Cleanliness: Magnetic Particle Inspection Procedure
  - 2301, Aircraft Quality Steel Cleanliness: Magnetic Particle

<sup>2</sup> Annual Book of ASTM Standards, Vol 01.05.

<sup>3</sup> Annual Book of ASTM Standards, Vol 05.01.

<sup>4</sup> Annual Book of ASTM Standards, Vol 03.01.

<sup>5</sup> Annual Book of ASTM Standards, Vol 03.03.

<sup>6</sup> Available from the Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096.

Inspection Procedure<sup>6</sup>

2303, Aircraft Quality Steel Cleanliness: Martensitic Corrosion-Resistant Steels Magnetic Particle Inspection Procedure

2304, Special Aircraft-Quality Steel Cleanliness: Magnetic Particle Inspection Procedure

2.4 *ISO Standards:*

ISO 3763, Wrought steels—Macroscopic methods for assessing the content of nonmetallic inclusions

ISO 4967, Steel—Determination of content of nonmetallic inclusions—Micrographic methods using standard diagrams

2.5 *ASTM Adjuncts:*

Inclusions in Steel Plates I-r and II<sup>7</sup>

Four Photomicrographs of Low Carbon Steel<sup>8</sup>

### 3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this practice, see Terminology E 7.

3.1.2 Terminology E 7 includes the term *inclusion count*; since some methods of these test methods involve length measurements or conversions to numerical representations of lengths or counts, or both, the term *inclusion rating* is preferred.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *aspect ratio*—the length-to-width ratio of a microstructural feature.

3.2.2 *discontinuous stringer*—three or more Type B or C inclusions aligned in a plane parallel to the hot working axis and offset by no more than 15  $\mu\text{m}$ , with a separation of less than 40  $\mu\text{m}$  (0.0016 in.) between any two nearest neighbor inclusions.

3.2.3 *inclusion types*—for definitions of sulfide-, alumina-, and silicate-type inclusions, see Terminology E 7. Globular oxide, in some methods refers to isolated, relatively nondeformed inclusions with an aspect ratio not in excess of 5:1. In other methods, oxides are divided into deformable and nondeformable types.

3.2.4 *JK inclusion rating*—a method of measuring nonmetallic inclusions based on the Swedish Jernkontoret procedures; Methods A and D of these test methods are the principal JK rating methods, and Method E also uses the JK rating charts.

3.2.5 *stringer*—an individual inclusion that is highly elongated in the deformation direction or three or more Type B or C inclusions aligned in a plane parallel to the hot working axis and offset by no more than 15  $\mu\text{m}$ , with a separation of less than 40  $\mu\text{m}$  (0.0016 in.) between any two nearest neighbor inclusions.

3.2.6 *worst-field rating*—a rating in which the specimen is rated for each type of inclusion by assigning the value for the highest severity rating observed of that inclusion type anywhere on the specimen surface.

### 4. Significance and Use

4.1 These test methods cover four macroscopical and five microscopical test methods for describing the inclusion content of steel and procedures for expressing test results.

4.2 Inclusions are characterized by size, shape, concentration, and distribution rather than chemical composition. Although compositions are not identified, microscopical methods place inclusions into one of several composition-related categories (sulfides, oxides, and silicates—the last as a type of oxide). Paragraph 12.2.6 describes a metallographic technique to facilitate inclusion discrimination. Only those inclusions present at the test surface can be detected.

4.3 The macroscopical test methods evaluate larger surface areas than microscopical test methods and because examination is visual or at low magnifications, these methods are best suited for detecting larger inclusions. Macroscopical methods are not suitable for detecting inclusions smaller than about 0.40 mm ( $1/64$  in.) in length and the methods do not discriminate inclusions by type.

4.4 The microscopical test methods are employed to characterize inclusions that form as a result of deoxidation or due to limited solubility in solid steel (indigenous inclusions). These inclusions are characterized by morphological type, that is, by size, shape, concentration, and distribution, but not specifically by composition. The microscopical methods are not intended for assessing the content of exogenous inclusions (those from entrapped slag or refractories) nor for rating the content of carbides, carbonitrides, nitrides, borides, or intermetallic phases, although they are sometimes used for this latter purpose.

4.5 Because the inclusion population within a given lot of steel varies with position, the lot must be statistically sampled in order to assess its inclusion content. The degree of sampling must be adequate for the lot size and its specific characteristics. Materials with very low inclusion contents may be more accurately rated by automatic image analysis (see Practice E 1122), which permits more precise microscopical ratings.

4.6 Results of macroscopical and microscopical test methods may be used to qualify material for shipment, but these test methods do not provide guidelines for acceptance or rejection purposes. Qualification criteria for assessing the data developed by these methods can be found in ASTM product standards or may be described by purchaser-producer agreements.

4.7 These test methods are intended for use on wrought metallic structures. While a minimum level of deformation is not specified, the test methods are not suitable for use on cast structures or on lightly worked structures.

## MACROSCOPICAL METHODS

### 5. Macroscopical Test Methods Overview

5.1 *Summary:*

5.1.1 *Macroetch Test*—The macroetch test is used to indicate inclusion content and distribution, usually in the cross section or transverse to the direction of rolling or forging. In some instances, longitudinal sections are also examined. Tests are prepared by cutting and machining a section through the desired area and etching with a suitable reagent. A solution of

<sup>7</sup> Available from ASTM Headquarters. Order ADJE004502.

<sup>8</sup> Available from ASTM Headquarters. Order ADJE004501.

one part hydrochloric acid and one part water at a temperature of 71 to 82°C (160 to 180°F) is widely used. As the name of this test implies, the etched surface is examined visually or at low magnification for inclusions. Details of this test are included in Method E 381. The nature of questionable indications should be verified by microscopical or other means of inspection.

5.1.1.1 Sulfides are revealed as pits when the standard etchant described in 5.1.1 is used.

5.1.1.2 Only large oxides are revealed by this test method.

5.1.2 *Fracture Test*—The fracture test is used to determine the presence and location of inclusions as shown on the fracture of hardened slices approximately 9 to 13 mm (3/8 to 1/2 in.) thick. This test is used mostly for steels where it is possible to obtain a hardness of approximately 60 HRC and a fracture grain size of 7 or finer. Test specimens should not have excessive external indentations or notches that guide the fracture. It is desirable that fracture be in the longitudinal direction approximately across the center of the slice. The fractured surfaces are examined visually and at magnifications up to approximately ten diameters, and the length and distribution of inclusions is noted. Heat tinting, or *blueing*, will increase visibility of oxide stringers. ISO 3763 provides a chart method for fracture surface inclusion ratings. In some instances, indications as small as 0.40 mm (1/64 in.) in length are recorded.

5.1.3 *Step-Down Method*—The step-down test method is used to determine the presence of inclusions on machined surfaces of rolled or forged steel. The test sample is machined to specified diameters below the surface and surveyed for inclusions under good illumination with the unaided eye or with low magnification. In some instances, test samples are machined to smaller diameters for further examination after the original diameters are inspected. This test is essentially used to determine the presence of inclusions 3 mm (1/8 in.) in length and longer.

5.1.4 *Magnetic Particle Method*—The magnetic particle method is a variation of the step-down method for ferromagnetic materials in which the test sample is machined, magnetized, and magnetic powder is applied. Discontinuities as small as 0.40 mm (1/64 in.) in length create magnetic leakage fields that attract the magnetic powder, thereby outlining the inclusion. See Section 6 for a detailed procedure.

### 5.2 Advantages:

5.2.1 These test methods facilitate the examination of specimens with large surface areas. The larger inclusions in steel, which are the main concern in most cases, are not uniformly distributed and the spaces between them are relatively large, so that the chances of revealing them are better when larger specimens are examined.

5.2.2 Specimens for macroscopical examination may be quickly prepared by machining and grinding. A highly polished surface is not necessary. The macroscopical methods are sufficiently sensitive to reveal the larger inclusions.

### 5.3 Disadvantages:

5.3.1 These test methods do not distinguish among the different inclusion shapes.

5.3.2 They are not suitable for the detection of small globular inclusions or of chains of very fine elongated inclusions.

5.3.3 The magnetic particle method can lead to incorrect interpretation of microstructural features such as streaks of retained austenite, microsegregation, or carbides in certain alloys; this is particularly likely if high magnetization currents are employed.

## 6. Magnetic Particle Method—Details of Procedure

### 6.1 Test Specimens:

6.1.1 The specimens shall be prepared in accordance with the details given in 6.2. The recommended procedure for removal from blooms, billets, and bars in round or square sections is as follows:

6.1.1.1 *Cross Sections over 230 cm<sup>2</sup> (36 in.<sup>2</sup>)*—Cut a quarter section as shown in Fig. 1 or 2 and prepare the specimen by machining, or forging and machining, to a straight cylinder of a diameter between 60 and 150 mm (2 1/2 and 6 in.). An alternative method is to forge or roll the full section to 150 mm (6 in.) square or round and machine the quarter section in accordance with 6.1.1.2.

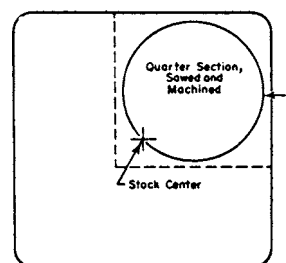
6.1.1.2 *Cross Sections 100 to 230 cm<sup>2</sup> (16 to 36 in.<sup>2</sup>) Inclusive*—Cut a quarter section as shown in Fig. 1 or Fig. 2 and prepare the specimen by machining, or forging and machining, to a straight cylinder of the largest possible diameter.

6.1.1.3 *Cross Sections Less than 100 cm<sup>2</sup> (16 in.<sup>2</sup>)*—Machine the specimen to a straight cylinder. An alternative method is to use a three diameter step-down specimen, each cylindrical section being 75 mm (3 in.) in length. The diameter, D, of the first step is the stock size less standard machining allowance; the diameter of the second step is 3/4 D; and the diameter of the third step is 1/2 D.

6.1.2 The specimens shall conform to the following requirements unless specified otherwise in 6.1.1.1-6.1.1.3:

6.1.2.1 The length of the rated surface is nominally 125 mm (5 in.). A 25 mm (1 in.) extension for holding is usually employed.

6.1.2.2 The minimum amount of stock removed from the surface shall be as follows:

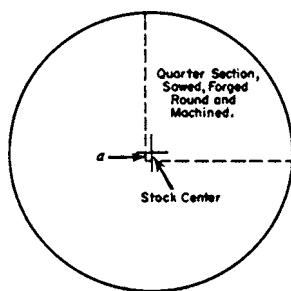


NOTE 1—This method is also applicable to round sections.

NOTE 2—a denotes surface removal.

FIG. 1 Quarter Section Specimen from Square Section for Magnetic Particle Test, Machine Only





NOTE 1—Method also applicable to square sections.

NOTE 2—*a* denotes distance equal to surface removal.

**FIG. 2 Quarter Section Specimen from Round Section for Magnetic Particle Test, Forging and Machining**

Nominal Stock Size, Round or Square, mm, (in.)	Minimum Stock Removal from the Surface, mm (in.)
To 12.7 (½)	0.76 (0.030)
Over 12.7 to 19 (½ to ¾)	1.13 (0.045)
Over 19 to 25.4 (¾ to 1)	1.52 (0.060)
Over 25.4 to 38 (1 to 1½)	1.89 (0.075)
Over 38 to 51 (1½ to 2)	2.28 (0.090)
Over 51 to 64 (2 to 2½)	3.17 (0.125)
Over 64 to 89 (2½ to 3½)	3.96 (0.156)
Over 89 to 115 (3½ to 4½)	4.75 (0.187)
Over 115 to 152 (4½ to 6)	6.35 (0.250)

6.1.2.3 All quarter sections shall be cut oversize as shown in Fig. 1 and Fig. 2 so that the center of the original stock will be approximately on the surface of the test specimen. The location of the center of the original stock shall be identified on the test specimen by means of a stamped mark.

6.2 Preparation of Specimen:

6.2.1 After the specimen is rough turned, heat treat it to a hardness of about 300 HB by oil or water quenching from well above the critical temperature and temper within the range 200 to 650°C (400 to 1200°F), depending upon the composition of the steel. Take care to avoid quenching cracks. The heat treatment tends to develop a more uniform structure hard enough to retain some residual magnetism, thus helping to hold the magnetic powder in place after the test.

6.2.2 After heat treatment, grind the specimen, including the ends, or otherwise clean to ensure good contact for magnetizing. Avoid cracks in the grinding checks. The grinding shall be transverse to the length of the specimen. Longitudinal scratches may be deep enough to retain the magnetic powder and obscure the inclusion determination.

6.2.3 Before magnetizing, thoroughly wash the specimen with a quick-drying solvent in order to remove grease and finger marks.

6.3 Procedure:

6.3.1 Circularly magnetize the specimen by passing direct current through it in the longitudinal direction for 1/5 to 1/2 s. The magnitude of the current shall be 160 A/cm to 470 A/cm (400 to 1200 A/in.) of the diameter of the specimen.

6.3.2 In general, use the wet continuous method where the specimen is covered with magnetic particle suspension during magnetization. Hardened steel specimens (50 HRC or higher) may be tested using the wet residual method by applying the suspension after magnetization. Take care not to disturb indications before inspection is completed. For a detailed

description of the various wet methods of magnetic particle inspection, see Practice E 709.

6.3.3 It is common practice to suspend the fine magnetic particles in kerosene or other light oil of about 40 SUS viscosity. Use about 7.7 g/L (1 oz/gal) of nonfluorescent magnetic particles per litre of oil. The suspension concentration of nonfluorescent particles shall be 1.0 to 2.0 % by volume when tested by demagnetizing and allowing to settle 30 to 45 min in an ASTM 100-mL cone-shaped graduated centrifuge tube. For a description of a cone-shaped centrifuge tube, see Test Methods D 96.

6.3.4 As an alternative to the oil-base system, an aqueous system can be used. When using an aqueous system, the evaporation rate should be monitored. Add water to maintain the proper level.

6.4 Examination of Specimen:

6.4.1 Examine the specimen under a well-diffused light. Standard white fluorescent lighting is satisfactory. In order to obtain the best dispersion, place the longitudinal axis of the light at right angles to the longitudinal axis of the specimen. The larger inclusions will be plainly visible and the relatively small inclusions may also be detected. If inclusions of 0.8 mm (1/32 in.) or smaller are of interest, it will be helpful to examine with a low-power hand magnifying glass. The magnetic powder indications produced by inclusions can be distinguished by an experienced operator from indications due to other causes such as cracks, flow lines, carbides, etc. Record the size of each indication appearing on the surface of the specimen.

6.4.2 The indications representing inclusions may be recorded by photography, diagrams, or by transferring to a receptor medium. For example, a solution of plastic coating material may be applied by aerosol or other means, then removed and mounted after drying. Specially prepared absorbent papers such as dye transfer (imbibition) papers or clean out films may also be used successfully. These products are available in various sizes and may be obtained from photographic supply houses. Ordinary transparent adhesive tapes will also lift the magnetic powder from the specimen for mounting on a card. The transfer methods are rapid, sufficiently accurate to provide indications suitable for examination under low-power magnification, and are more accurate than photography on curved surfaces. Additionally, the transfer methods maintain the locations of indications in the specimen with respect to the original surface and centerline of the material.

6.5 Expression of Results:

6.5.1 Magnetic particle test results are normally expressed in terms of frequency and severity.

6.5.2 Frequency is the total number of indications in a given area. A commonly used reference area has been 258 cm<sup>2</sup> (40 in.<sup>2</sup>). Frequency may also be expressed in terms of number of indications per unit area of surface examined. The method of evaluating inclusions per square inch for frequency and severity has been adopted by the Society of Automotive Engineers in SAE J41. Refer to Aerospace Materials Specifications 2300, 2301, 2303, and 2304.

6.5.3 Severity is the weighted value of the magnetic particle indications in accordance with the following table taken from AMS specifications 2300, 2301, 2303, and 2304.

From AMS 2300 and 2304 Length of Indication, mm (in.)	Progression Factor for Severity Rating
0.4 to 0.8 ( $\frac{1}{64}$ to $\frac{1}{32}$ ) exclusive	2
0.8 to 1.6 ( $\frac{1}{32}$ to $\frac{1}{16}$ ) exclusive	4
1.6 to 3.2 ( $\frac{1}{16}$ to $\frac{1}{8}$ ) exclusive	16
3.2 ( $\frac{1}{8}$ ) and over	256
From AMS 2301 and 2303 Length of Indication, mm (in.)	Progression Factor for Severity Rating
1.6 to 3.2 ( $\frac{1}{16}$ to $\frac{1}{8}$ ) inclusive	0.5
3.2 to 6.4 ( $\frac{1}{8}$ to $\frac{1}{4}$ ) inclusive	1
6.4 to 12.8 ( $\frac{1}{4}$ to $\frac{1}{2}$ ) inclusive	2
12.8 to 19 ( $\frac{1}{2}$ to $\frac{3}{4}$ ) inclusive	4
19 to 25.4 ( $\frac{3}{4}$ to 1) inclusive	8
over 25.40 to 38.10 (over 1 to 1- $\frac{1}{2}$ ) inclusive	16

6.5.3.1 The severity value is obtained by multiplying the number of indications of a given length by the weight factor and adding these results. Severity should be expressed as the weighted value for a given area. Severity may also be expressed as the weighted value per unit area of surface examined (see AMS Specifications 2300, 2301, 2303, and 2304).

6.5.4 The averages of the frequency and severity values for all the specimens in a heat may be used to express the magnetic particle results for the heat.

6.5.5 The frequency and severity values for one heat may be readily compared with the values of another heat. In making such comparisons between heats, however, exercise care to compare results obtained only on billets or bars of approximately the same size.

6.5.6 If a step-down test is used, results should be related to the individual diameters.

6.5.7 Magnetic particle results may also be expressed as the total length of indications for a stated area. In the AMS standards described above, inclusion length per square inch is determined.

## MICROSCOPICAL METHODS

### 7. Microscopical Test Methods Overview

7.1 Microscopical methods are used to characterize the size, distribution, number, and type of inclusions on a polished specimen surface. This may be done by examining the specimen with a light microscope and reporting the types of inclusions encountered, accompanied by a few representative photomicrographs. This method, however, does not lend itself to a uniform reporting style. Therefore, standard reference charts depicting a series of typical inclusion configurations (size, type, and number) were created for direct comparison with the microscopical field of view.

7.2 Various reference charts of this nature have been devised such as the JK chart<sup>9</sup> and the SAE chart found in SAE Recommended Practice J422 of the SAE Handbook. The microscopical methods in Test Methods E 45 use refined comparison charts based on these charts. Method A (Worst Fields), Method D (Low Inclusion Content) and Method E (SAM Rating) use charts based on the JK chart while Method

C (Oxides and Silicates) uses the SAE chart. ISO Standard 4967 also uses the JK chart.

7.3 No chart can represent all of the various types and forms of inclusions. The use of any chart is thus limited to determining the content of the most common types of inclusions, and it must be kept in mind that such a determination is not a complete metallographic study of inclusions.

7.4 An alternate to comparison (chart) methods such as Methods A, C and D<sup>10</sup> may be found in Method B. Method B (Length) is used to determine inclusion content based on length. Only inclusions 0.127 mm (0.005 in.) or longer are recorded regardless of their type. From this method one may obtain data such as length of the longest inclusion and average inclusion length. In addition, photomicrographs may also be taken to characterize the so called *background inclusions* that were not long enough to measure.

7.5 The advantages of the microscopical methods are:

7.5.1 Inclusions can be characterized as to their size, type, and number.

7.5.2 Extremely small inclusions can be revealed.

7.6 A disadvantage of the microscopical methods is that individual rating fields are very small (0.50 mm<sup>2</sup>). This limits the practical size of the specimen as it would simply take a prohibitive number of fields to characterize a large specimen. The result obtained by a microscopical characterization of the inclusions in a large section is governed by chance if local variations in the inclusion distribution are substantial. The end use of the product determines the importance of the microscopical results. Experience in interpreting these results is necessary in order not to exaggerate the importance of small inclusions in some applications.

7.7 In determining the inclusion content, it is important to realize that, whatever method is used, the result actually applies only to the areas of the specimens that were examined. For practical reasons, such specimens are relatively small compared with the total amount of steel represented by them. For the inclusion determination to have any value, adequate sampling is just as necessary as a proper method of testing.

7.8 Steel often differs in inclusion content not only from heat to heat, but also from ingot to ingot in the same heat and even in different portions of the same ingot. It is essential that the unit lot of steel, the inclusion content of which is to be determined, shall not be larger than one heat. Sufficient samples should be selected to represent the lot adequately. The exact sampling procedure should be incorporated in the individual product requirements or specifications. For semifinished products, the specimens should be selected after the material has been sufficiently cropped and suitable discards made. If the locations of the different ingots and portions of ingots in the heat cannot be identified in the lot being tested, random sampling should involve a greater number of test specimens for an equivalent weight of steel. A value for the inclusion content

<sup>9</sup> The JK chart derives its name from its sponsors Jernkontoret, the Swedish Ironmasters Association.

<sup>10</sup> Note that while these methods are called comparison chart methods, the procedure used may also consist of length measurements or counts of inclusions, or both.

of an isolated piece of steel, even if accurately determined, should not be expected to represent the inclusion content of the whole heat.

7.9 The size and shape of the wrought steel product tested has a marked influence on the size and shape of the inclusions. During reduction from the cast shape by rolling or forging, the inclusions are elongated and broken up according to the degree of reduction of the steel cross section. In reporting results of inclusion determinations, therefore, the size, shape, and method of manufacture of the steel from which the specimens were cut must be stated. In comparing the inclusion content of different steels, they must all be rolled or forged as nearly as possible to the same size and shape, and from cast sections of about the same size. Specimens cut lengthwise or parallel to the direction of rolling or forging shall be used.

7.10 It may be convenient, in order to obtain more readily comparable results, to forge coupons from larger billets. These forged sections may then be sampled in the same way as rolled sections. Exercise care, however, to crop specimens of sufficient length from the billets for forging; otherwise, there is danger of the shear-dragged ends being incorporated in the specimens. Such distorted material will give a false result in the inclusion determination. To avoid this, it is helpful to saw the ends of the billet length for forging and to take the specimen from the middle of the forged length.

7.11 Several of the methods described in these test methods require that a specific area of the prepared surface of the specimen be surveyed, and all the significant inclusions observed be recorded and expressed in the results. The reported result for each specimen examined is, therefore, a more accurate representation of the inclusion content than a photomicrograph or diagram. A disadvantage of the Worst Field approach is that no such distribution of inclusion ratings is obtained.

7.12 To make comparisons possible between different heats and different parts of heats, the results shall be expressed in such a manner that an average for the inclusion content of the different specimens in the heat can be obtained. When the lengths of the inclusions are measured, the simplest number is that for the aggregate length of all the inclusions per area examined; however, it may be desirable not merely to add the lengths but also to weight the inclusions according to their individual lengths. The length of the largest inclusion found and the total number of inclusions may also be expressed.

## 8. Sampling

8.1 To obtain a reasonable estimate of inclusion variations within a lot, at least six locations, chosen to be as representative of the lot as possible, should be examined. In this context, a lot shall be defined as a unit of material processed at one time and subjected to similar processing variables. In no case should more than one heat be in the same lot. For example if a lot consists of one heat, sampling locations might be in the product obtained from the top and bottom of the first, middle, and last usable ingots in the pouring sequence. For strand cast or bottom pour processing, a similar sampling plan per heat should be invoked.

8.2 For cases in which a definite location within a heat, ingot, or other unit lot is unknown, statistical random sampling with a greater number of specimens should be employed.

8.3 Ratings obtained will vary with the amount of reduction of the product. For materials acceptance or for comparison among heats, care must be taken to sample at the correct stage of processing.

## 9. Test Specimen Geometry

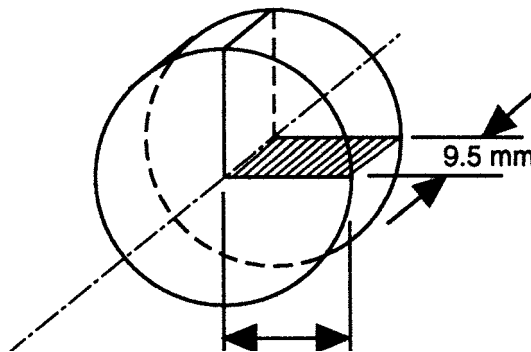
9.1 The recommended polished surface area of a specimen for the microscopical determination of inclusion content is 160 mm<sup>2</sup> (0.25 in.<sup>2</sup>). The polished surface must be parallel to the longitudinal axis of the product. In addition, for flat-rolled products, the section shall also be perpendicular to the rolling plane; for rounds and tubular shapes, the section shall be in the radial direction.

9.2 *Thick Section (Product Section Size Greater than 9.5 mm (0.375 in.) Thick, Such as Forgings, Billet, Bar, Slab, Plate, and Pipe):*

9.2.1 For wide products, the one-quarter point along the product width is commonly used to provide representative material.

9.2.2 For round sections, the manner of cutting a specimen from a 38 mm (1.5-in.) diameter section is shown in Fig. 3. A disk about 9.5 mm (0.375 in.) thick is cut from the product. The quarter-section indicated in Fig. 3 is cut from the disk and the shaded area is polished. Thus the specimen extends 9.5 mm along the length of the product from the outside to the center.

9.2.3 For large sections, each specimen shall be taken from the mid-radius location, as shown by the shaded area in Fig. 4. The specimen face to be polished extends 9.5 mm parallel to the longitudinal axis of the billet and 19 mm (0.75 in.) in the longitudinal radial plane, with the polished face midway between the center and the outside of the billet. Such midway sampling is used to decrease the number of specimens polished and examined. Other areas, such as the center and the surface, may be examined as well, provided the sampling procedure used is stated in the results. A billet or bar about 50 to 100 mm (2 to 4 in.) round or square is the preferred size from which



NOTE 1—Inch-pound equivalents: 9.5 mm = 3/8 in.; 19 mm = 3/4 in.  
**FIG. 3 Specimen from 1½-in. (38.1 mm) Round Section for Microscopical Test**