Designation: E 1122 – 96 (Reapproved 2002)

Standard Practice for Obtaining JK Inclusion Ratings Using Automatic Image Analysis[1]

This standard is issued under the fixed designation E 1122; 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 (ϵ) 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 This practice covers procedures to perform JK-type inclusion ratings using automatic image analysis in accordance with microscopical methods A and D of Practice E 45.

1.2 This practice deals only with the recommended test methods and nothing in it should be construed as defining or establishing limits of acceptability for any grade of steel or other alloy where the method is appropriate.

1.3 The values stated in SI units are to be regarded as the standard. Values in parentheses are conversions and are approximate.

1.4 *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:*

E 3 Guide for Preparation of Metallographic Specimens[2]

E 7 Terminology Relating to Metallography[2]

E 45 Test Methods for Determining the Inclusion Content of Steel[2]

E 768 Practice for Preparing and Evaluating Specimens for Automatic Inclusion Assessment of Steel[2]

E 1245 Practice for Determining the Inclusion or Second-Phase Constituent Content of Metals by Automatic Image Analysis[2]

2.2 *ASTM Adjuncts:*

Inclusions in Steel, Plates I and III[3]

Colored Plate Illustrating Use of DIC for Evaluating the Quality of Specimen Preparation[4]

3. Terminology

3.1 *Definitions*—For definitions of terms used in this practice, see Terminology E 7.

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 inclusions separated by less than 40 µm (0.0016 in.) that are aligned in a plane parallel to the hot-working axis.

3.2.3 *stringer*—an individual inclusion that is highly elongated in the deformation direction, or three or more inclusions separated by less than 40 µm (0.0016 in.) and aligned in the same plane parallel to the deformation direction.

3.2.4 *threshold setting*—isolation of a range of gray level values exhibited by one constituent in the microscope field.

4. Summary of Practice

4.1 The inclusions on the surface of a properly prepared as-polished metallographic specimen are viewed with a high-quality, metallurgical microscope. The bright-field image is picked up by a suitable television camera and transferred to the image analyzer screen. For the manual Method D in Practice E 45, each 0.50-mm^2 test area is examined at 100X, classified and rated before moving to the next contiguous field until a total area of 160 mm^2 is covered. Using image analysis, the 160-mm^2 area can be examined at any desired magnification and field area. The inclusions are classified by type and thickness. Then, severity values are determined based upon the required 0.50-mm^2 field areas. Hence, with image analysis, the examination field size may be larger or smaller than 0.50 mm^2 as long as the severity calculations are based on 0.50-mm^2 subdivisions of the 160-mm^2 total examination area.

4.2 Inclusion types (A, B, C, and D in accordance with microscopical Practice E 45) are separated based on gray-level differences and morphology. These inclusions are the indigenous types resulting from the deoxidation of steel and the precipitation of sulfide during solidification. Sulfides (Type A) are separated from oxides (Types B, C, and D) based on gray level. All of the oxides are lower in light reflectivity than the sulfides. The oxides are separated based on morphology: *Type*

[1] 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 May 10, 1996. Published July 1996. Originally published as E 1122 – 92. Last previous edition E 1122 – 96.

[2] *Annual Book of ASTM Standards*, Vol 03.01.

[3] Available from ASTM Headquarters. Order PCN 12-500450-01.

[4] Available from ASTM Headquarters. Order PCN 12-507680-22.

B—discontinuous stringers; *Type C*—solid stringers; and *Type D*—non-stringer, globular particles.

4.3 Each inclusion type is further categorized as thin or thick (heavy) based on the thickness of the inclusions in accordance with the limits in Table 1 (Inclusion Width Parameters (Method D)) of Practice E 45.

4.4 The inclusion rating numbers for thin and thick categories of each inclusion type are calculated based on the total length per field for Type A, the total stringer lengths per field for Types B and C, and on the number of inclusions per field for Type D inclusions in accordance with the limits in Table 2 (Minimum Values for Inclusion Rating Numbers (Methods A and D)) of Practice E 45. Traditionally, severity ratings using Plate I are made to whole severity units while ratings using Plate III are made to half-severity units. Either plate may be used with Method A of Practice E 45 but only Plate III is used with Method D. Severity values are always rounded downward to the nearest half or whole unit from 0 to 5. For steels with particularly low inclusion contents, severity values may be rounded down to the nearest quarter or tenth value, per agreement between producer and purchaser. However, because of the way D inclusion counts are defined (for 1 inclusion, the severity is 0.5 and for 0 inclusions, the severity is 0), there can be no subdivisions between 0 and 0.5 severities.

4.5 The inclusion ratings for each type present in each measured field are stored in the computer memory during analysis.

4.6 The inclusions are rated within a total contiguous area of 160 mm^2 on the plane of polish. The number of fields required to cover this area depends upon the area examined per field, as described in 4.1. Fields are selected in a contiguous, square or rectangular grid pattern using an X- and Y-stage system. The total number of fields to be measured can be altered by producer-purchaser agreements.

4.7 After the analysis, the results are printed listing the number of fields with each possible severity rating, for each type and thickness category inclusion present (corresponding to Practice E 45, Method D).

4.8 If worst-field ratings are desired rather than quantitative ratings, they can be determined from the quantitative printout of results; or, only the highest severity level for each inclusion type and thickness may be stored during the analysis (corresponds to Practice E 45, Method A).

4.9 Carbides, nitrides, carbonitrides and borides are not evaluated and rated using this procedure. However, based upon producer-purchaser agreements, such ratings may be made. Guidelines for performing such ratings are not included in this practice.

4.10 Modified quantitative rating procedures may be made based on agreements between producers and purchasers. Such modifications pertain to the types and severities counted and methods to summarize results in the form of quality indexes. Such procedures are not defined in this practice.

TABLE 1 Inclusion Width Parameters

Inclusion Type	Thin		Thick (Heavy)		Oversize
	Minimum Width (µm)	Maximum Width (µm)	Minimum Width (µm)	Maximum Width (µm)	Minimum Width (µm)
A	≥2	4	>4	12	>12
B	≥2	9	>9	15	>15
C	≥2	5	>5	12	>12
D	≥3	8	>8	13	>13

TABLE 2 Minimum Values for Inclusion Severity Rating Levels (Expressed in Different Measurement Units)

Proposed Practice E 45 Rating Limits (in. at 100X or count)				
Severity	A	B	C	D
0.5	0.15	0.07	0.07	1
1.0	0.50	0.30	0.30	4
1.5	1.03	0.72	0.69	9
2.0	1.72	1.35	1.26	16
2.5	2.56	2.19	2.01	25
3.0	3.54	3.24	2.94	36
3.5	4.65	4.52	4.05	49
4.0	5.90	6.02	5.35	64
4.5	7.47	7.77	6.84	81
5.0	8.78	9.75	8.52	100
(mm at 100X, or count)				
Severity	A	B	C	D
0.5	3.7	1.7	1.8	1
1.0	12.7	7.7	7.6	4
1.5	26.1	18.4	17.6	9
2.0	43.6	34.3	32.0	16
2.5	64.9	55.5	51.0	25
3.0	89.8	82.2	74.6	36
3.5	118.1	114.7	102.9	49
4.0	149.8	153.0	135.9	64
4.5	189.8	197.3	173.7	81
5.0	223.0	247.6	216.3	100
(µm at 1X, or count)				
Severity	A	B	C	D
0.5	37.0	17.2	17.8	1
1.0	127.0	76.8	75.6	4
1.5	261.0	184.2	176.0	9
2.0	436.1	342.7	320.5	16
2.5	649.0	554.7	510.3	25
3.0	898.0	822.2	746.1	36
3.5	1181.0	1147.0	1029.0	49
4.0	1498.0	1530.0	1359.0	64
4.5	1898.0	1973.0	1737.0	81
5.0	2230.0	2476.0	2163.0	100
(mm/mm^2, or $count/mm^2$)				
Severity	A	B	C	D
0.5	0.074	0.034	0.036	2
1.0	0.254	0.154	0.152	8
1.5	0.522	0.368	0.352	18
2.0	0.872	0.686	0.640	32
2.5	1.298	1.110	1.020	50
3.0	1.796	1.644	1.492	72
3.5	2.362	2.294	2.058	98
4.0	2.996	3.060	2.718	128
4.5	3.796	3.946	3.474	162
5.0	4.460	4.952	4.326	200

5. Significance and Use

5.1 This practice covers automatic image analysis procedures for rating the inclusion content of steels in accordance with Practice E 45 and guides for expressing the measurement values.

5.2 This practice is primarily intended for rating the inclusion content of steels deoxidized with silicon or aluminum, both silicon and aluminum, or vacuum-treated steels without either silicon or aluminum additions. Guidelines are provided to rate inclusions in steels treated with rare earth additions or calcium-bearing compounds. When such steels are evaluated, the test report should describe the nature of the inclusions rated according to each inclusion category (A, B, C, D).

5.3 This practice is primarily established to provide a quantitative rating (Method D of Practice E 45) of the inclusion content in half-severity number increments from 0 to 5 for each inclusion type and thickness. By agreements between producer and purchaser, this practice may be modified to count only certain inclusion types and thicknesses, or only those inclusions above a certain severity level, or both. Procedures to define inclusion content indices are not defined in this standard but may be used based on producer-purchaser agreements.

5.4 Qualitative practices may also be used where only the highest severity ratings for each inclusion type and thickness are defined or the number of fields containing these highest severity ratings are tabulated. Such modified reporting practices must be established by producer-purchaser agreement.

5.5 In addition to the Practice E 45 JK ratings, basic (such as used in Practice E 1245) stereological measurements (for example, the volume fraction of sulfides and oxides, the number of sulfides or oxides per square millimetre, the spacing between inclusions, and so forth) may be separately determined and added to the test report, if desired for additional information. This practice, however, does not address the measurement of such parameters.

5.6 The quantitative results are intended to provide a description of the types and amounts of indigenous inclusions in a heat of steel for use in quality control or purchase requirements. This practice contains no guidelines for such use.

5.7 This practice categorizes inclusions only on the basis of light reflectivity, morphology, thickness, length, and number. No information is obtained regarding inclusion composition. Other analytical procedures may be employed to define the inclusion compositions separated according to the JK categories.

6. Apparatus

6.1 *Microscope*, a high-quality metallurgical, upright or inverted, equipped with suitable low-power bright-field-type objectives and either a manual or automated stage, is used to image the inclusions. Field selection is simpler with the upright-type microscope. An automated stage reduces operator fatigue.

6.2 *Automatic Image Analyzer*, television-type, with a pick-up tube with adequate sensitivity to separate sulfides from oxides at relatively low magnification, is required.

6.2.1 The image analyzer must be capable of distinguishing between stringered oxides and isolated globular oxides. The image analyzer must also be capable of separating the stringered oxides according to the difference in morphology (Type B or C) and measure the stringer lengths per field of each type. All oxides not included in Type B or C stringers are separated and counted as Type D oxides. For each type (A, B, C, D) so separated, the image analyzer must be capable of measuring the thickness of the inclusion or stringer and separate each type as thin or thick (heavy).

6.2.2 The image analyzer must have a computer with sufficient memory to store the ratings of the number of fields as a function of severity rating, inclusion type, and thickness after the severities are calculated.

6.3 *Special Considerations*—The environment housing the test equipment must be controlled. Computer equipment requires control of temperature and humidity. The air must be relatively dust free. Dust that settles on the specimen surface during analysis will influence test results.

7. Sampling

7.1 Sampling is done in accordance with the guidelines given in Practice E 45.

8. Test Specimens

8.1 The location and orientation of test specimens shall be as described in Practice E 45. In all cases, the polished surface shall be parallel to the hot-working axis. Studies have demonstrated that inclusion length measurements are significantly affected if the plane of polish is angled more than 6° from the longitudinal hot-working direction.[5] Test specimens should not be cut from areas influenced by shearing which alters the true orientation of the inclusions.

8.2 The surface to be polished must be at least 160 mm^2 (0.25 $in.^2$) in area. It is recommended that a significantly large area should be obtained so that the measurements may be made within the defined area away from the edges of the sample.

9. Specimen Preparation

9.1 Metallographic specimen preparation must be carefully controlled to produce acceptable quality surfaces for image analysis. Guidelines and recommendations are given in Methods E 3, and Practices E 45 and E 768.

9.2 Polishing must reveal the inclusions without interference from artifacts, foreign matter, or scratches. Polishing must not alter the true appearance of the inclusions by excessive relief, pitting, and pull-out. Use of automatic grinding and polishing devices is recommended.

9.3 Inclusion retention is generally easier to accomplish in hardened steel specimens than in the annealed condition. If inclusion retention is inadequate in annealed specimens, they should be subjected to a standard heat treatment cycle using a relatively low tempering temperature. After heat treatment, the specimen must be descaled and the longitudinal plane must be reground below any decarburization. This recommendation only applies to heat-treatable steel grades.

9.4 Mounting of specimens is not required if unmounted specimens can be properly polished.

9.5 Establishment of the polishing practice should be guided by Practice E 768.

10. Calibration and Standardization

10.1 A stage micrometer and a ruler, both calibrated against devices traceable to a recognized national standards laboratory, such as the National Institute for Standards and Technology (NIST), are used to determine the magnification of the system and calibrate the system in accordance with the manufacturer's

[5] Allmand, T. R., and Coleman, D. S., "The Effect of Sectioning Errors on Microscopic Determinations of Non-Metallic Inclusions in Steels," *Metals and Materials*, Vol 7, 1973, pp. 280–283.

recommended procedure. For example, the ruler is superimposed over the magnified image of the stage micrometer on the monitor. The apparent (magnified) distance between two known points on the stage micrometer is measured with the ruler. The magnified distance is divided by the true distance to determine the screen magnification. The pixel dimensions can be determined from the number of pixels for a known horizontal or vertical dimension on the monitor. Divide the known length of a scale or mask by the number of pixels representing that length on the monitor to determine the pixel size for each possible screen magnification. Not all systems use square pixels. Determine the pixel dimensions in both horizontal and vertical orientations. Check the instruction manual to determine how corrections are made for those systems that do not use square pixels.

10.2 Follow the manufacturer's recommendations in adjusting the microscope light source and setting the correct level of illumination for the television video camera. For systems with 256 gray levels, the illumination is generally adjusted until the as-polished matrix surface is at level 254 and black is at zero.

10.3 For modern image analyzers with 256 gray levels, with the illumination set as described in 10.2, it is usually possible to determine the reflectance histogram of individual inclusions as an aid in establishing proper threshold settings to discriminate between oxides and sulfides. Oxides are darker and usually exhibit gray levels below about 130 on the gray scale while the lighter sulfides generally exhibit values between about 130 and 195. These numbers are not absolute and will vary somewhat for different steels and different image analyzers. After setting the threshold limits to discriminate oxides and sulfides, use the *flicker method* of switching back-and-forth between the live inclusion image and the detected (discriminated) image, over a number of test fields, to ensure that the settings are correct, that is, detection of sulfides or oxides by type and size is correct.

11. Procedure

11.1 Place the specimen on the microscope stage so that the specimen surface is perpendicular to the optical axis. With an inverted-type microscope, simply place the specimen face-down on the stage plate and hold in place with the stage clamps. With an upright-type microscope, place the sample on a slide and level the surface using clay or plasticene and a hand-leveling press. Certain upright microscopes can be equipped with an autoleveling stage for mounted specimens. If the sample must be leveled using clay, the tissue paper placed between the specimen surface and the leveling press ram may adhere to the surface and present artifacts for measurement. In some cases, adherent tissue can be blown off the specimen surface. An alternative procedure to avoid this problem is to place an aluminum or stainless steel ring form, which has been flattened slightly in a vise to an oval shape, between the sample and the ram. If the specimen was mounted, the ring form will rest only on the surface of the mounting material. If the specimen is unmounted but with a surface area substantially greater than the 160-mm^2 area required for the measurement, the ring form can rest on the outer edges of the specimen for flattening and thus avoid contact with the measurement area. Align the specimen on the stage so that the inclusions are aligned parallel to the *x*-direction of the stage movement, that is, horizontal on the monitor screen. Alternatively, if programming is facilitated, align the inclusions parallel to the *y*-direction of the stage movement, that is, the longitudinal direction is vertical on the monitor screen.

11.2 Check the microscope light source for correct alignment and adjust the illumination to the level required by the television video camera.

11.3 The inclusions can be examined and discriminated by type using magnifications other than 100X and field areas other than 0.50 mm^2 as long as the severity measurements are based upon the required 0.50-mm^2 field area (see 4.1), if the image analyzer is capable of such a procedure.[6] If the system cannot work in this manner, that is, if the inclusions in each field must be discriminated by type, measured, and a severity level assigned on a field-by-field basis, then the magnification must be chosen so that the field area is as close to 0.50 mm^2 as possible. A deviation of less than $\pm$0.05 mm^2 from the required 0.50-mm^2 area will not significantly impair measurement results. The magnification chosen should produce pixel height of no more than 2 µm, but preferably about 1 µm.

11.4 Select the gray-level threshold settings as described in 10.3 to permit independent detection of sulfides and oxides.

11.5 When detecting sulfides, a false image (called the *halo effect*) may be detected around the periphery of oxides in the same field. This problem can be corrected by the use of an auto-delineation feature or by application of appropriate algorithms to the binary image. Choice of the most satisfactory approach depends upon the image analysis system used.

11.6 Set the stage controls to move the specimen in a square or rectangular pattern with contiguous field alignment so that a total area of 160 mm^2 is examined and evaluated. Other measurement areas may be used based on producer-purchaser agreements.

11.7 Use a previously written computer program, described in Section 12, to separate the inclusion images by type and thickness, calculate severities based on length or number, store results, control stage movements (if an automated stage is used), and generate the test report.

11.8 The program should incorporate procedures to deal with fields that contain artifacts, either from polishing or cleaning, or from dust settling on the specimen, and so forth. Depending on the system and the nature of the artifact, it may be possible to develop an algorithm that will recognize such artifacts and remove them from the binary image. If this cannot be done, the field should be rejectable, that is, no test results from the field should be stored. In such a case, another field should be analyzed to replace the rejected field, if this is possible. If a rejected field cannot be replaced in the same run, it may be possible to evaluate and rate the additional fields required in a subsequent run (do not rate fields already rated). Good preparation practices will minimize the need to reject fields with artifacts. In no case should the test results for a

[6] Forget, C., "Improved Method for E1122 Image Analysis Nonmetallic Inclusion Ratings," *MiCon 90: Advances in Video Technology for Microstructural Control, ASTM STP 1094*, American Society for Testing and Materials, Philadelphia, 1991, pp. 135–150.

measurement area less than 160 mm^2 be mathematically extrapolated or converted (for example, because of rejected fields) in an effort to produce data for a 160-mm^2 area.

11.9 The computer program may also contain procedures to perform basic (see Practice E 1245) stereological measurements to supplement the JK analyses. Such measurements are not covered by this practice.

12. Classification of Inclusions and Calculation of Severities

12.1 The inclusions are classified into four categories, A to D as described in Practice E 45, based on their morphology, and into two subcategories based on their thickness. The morphologies of Types A and C are quite similar; but, historically, Type A refers to sulfides while Type C refers to deformable oxides, for example, manganese silicates. Hence, the Type A inclusions are light gray in appearance while the Type C inclusions are black.

12.1.1 Type A inclusions (sulfides) are separated from Type B, C, or D oxides based on gray level differences. Type B, C, or D are discriminated based upon their morphological differences. Types B and C exist as stringers. The B-type stringers consist of a number (at least three) of round or angular oxide particles with aspect ratios less than 5 that are aligned nearly parallel to the deformation axis. Particles within ±15 µm of the centerline of a B-type stringer are considered to be part of that stringer. The C-type stringers consist of only a few highly elongated oxides with smooth surfaces aligned parallel to the deformation axis. Aspect ratios are generally high, ≥5. The maximum permitted separation between particles in a stringer is 40 µm. Any oxides that have aspect ratios <5, and are not part of a B- or C-type stringer, are rated as D-types. No other shape restriction is applicable. The alignment of Type A, B, and C inclusions in wrought specimens generally will not deviate by more than ±20° from the longitudinal direction. By restricting the orientation of detected features within this limit, certain artifacts (for example, deep scratches not removed during polishing) can be recognized and deleted from the binary image, if their orientation is greater than this limit.

NOTE 1—The discrimination and measurement approaches used in the computer program, based on the above restrictions, depend upon the system and its capabilities. Different approaches are possible and their success should be evaluated.

12.1.2 After the inclusions are categorized by type, they must be categorized by thickness or diameter, that is, thin or thick (heavy) as shown in Table 1 (Table 3 on Inclusion Width Parameters (Method D) in Practice E 45). Determine the average thickness or maximum diameter of each inclusion. Inclusions thinner than 2 µm in width, or 3 µm in diameter for D inclusions, are not rated, that is, their lengths are not included in subsequent calculations of inclusion severities. If the width of an A inclusion, or a B or C stringer, varies and becomes less than 2 µm over part of its length, detect as much of it as possible and calculate the severity based on the detected length. For specimens from wrought products with high degrees of reduction, where the majority of the inclusions are <2 µm thick, based on producer-purchaser agreement, the minimum thickness of the thin series can be set at a lower value, such as 0.5 µm, or the lower limit can be dropped. Detection of these thinner inclusions will require use of a higher magnification with a resultant field size less than 0.50 mm^2; hence, field data must be combined, as described in 11.3, to obtain valid ratings.

12.1.3 Type A sulfides with average widths between 2 and 4 µm are rated as thin, those >4 up to 12 µm wide are rated as thick (heavy), while those >12 µm in width are oversized and rated separately.

12.1.4 The individual inclusions within each B-type stringer are categorized as thin (2 to 9 µm in width), thick (>9 to 15 µm), or oversized (>15 µm in width). The lengths of the thin, thick, or oversized particles in the stringer are summed by type. Whichever type is ≥50 % of the total length of the particles in the stringer determines whether the stringer is rated as thin, thick, or oversized (the latter are reported separately).

12.1.5 The individual inclusions in C-type stringers are treated in the same manner as described in 12.1.4 except that thins are 2 to 5 µm in width, thicks are >5 to 12 µm in width, and the oversized inclusions are >12 µm in width. Oversized C-types are reported separately.

12.1.6 The D-type inclusions are classified as thin (3 to 8 µm in width), thick (>8 to 13 µm in width), and oversized (>13 µm in width) based on their maximum diameter. D-types have aspect ratios <5 and are not part of a stringer. There is no shape requirement for D-types other than the maximum aspect ratio. Oversized D-types are reported separately.

TABLE 3 Regression Equations for Severity Rating Calculations (Based on the Four Alternate Ways of Expressing A, B, or C Lengths or Two Ways to Express D Counts in Table 2)

1. Length in in. at 100X or count per field	
A	Log(Sev.) = [0.560522Log(A)] + 0.168870
B	Log(Sev.) = [0.462631Log(B)] + 0.241092
C	Log(Sev.) = [0.480736Log(C)] + 0.252106
D	Log(Sev.) = [0.5Log(D)] − 0.30102
2. Length in mm at 100X or count per field	
A	Log(Sev.) = [0.561739Log(A)] − 0.62003
B	Log(Sev.) = [0.463336Log(B)] − 0.41017
C	Log(Sev.) = [0.479731Log(C)] − 0.42132
D	Log(Sev.) = [0.5Log(D)] − 0.30102
3. Length in µm at 1X or count per field	
A	Log(Sev.) = [0.561739Log(A)] − 1.18177
B	Log(Sev.) = [0.463336Log(B)] − 0.8735
C	Log(Sev.) = [0.479731Log(C)] − 0.90105
D	Log(Sev.) = [0.5Log(D)] − 0.30102
4. Length per unit area (mm/mm^2) or count per unit area ($no./mm^2$)	
A	Log(Sev.) = [0.561739Log(A)] − 0.33434
B	Log(Sev.) = [0.463336Log(B)] − 0.377021
C	Log(Sev.) = [0.479731Log(C)] − 0.393723
D	Log(Sev.) = [0.5Log(D)] − 0.45154

NOTE 1—Choose the equations to calculate the inclusion severity (both thin and heavy series) based on the nature of the measurement used; all approaches give the same severity values.

NOTE 2—Round off the severity number downward to the nearest half-severity level (or, if desired, to the nearest one-quarter or one-tenth value). For D-type inclusions, because we have only whole integer counts, and 0.5 is the severity for one inclusion in a field (a field has an area of 0.5 mm^2), there cannot be a D severity of 0.25 or any one-tenth value below 0.5, except for 0 if there are no ratable Ds present.

NOTE 3—To determine the severity value using the above equations, take the Log (base 10) of the measured value, multiply by the indicated value, subtract or add the indicated value, then take the antilog and round downward as described above.

NOTE 2—Several approaches may be used to determine the average width of inclusions. The approach selected should be evaluated to determine if it is satisfactory.

12.1.7 Oxides located at the tips of elongated Type A sulfides, unless they are close enough together to meet the requirements of a B-type stringer (and there are three or more), are rated as D-types.

12.1.8 The indigenous inclusions in steels deoxidized with rare earth elements or calcium-containing materials are also classified by morphology and thickness with the added requirement that compositional information be given in the report. For example, rare earth or calcium-modified sulfides with an aspect ratio ≥5 are rated as A-types by their total length per field according to the limits of Table 2 and the width limits of Table 1. However, for aspect ratios <5, and if they are not part of a stringer, they are rated as D-types by their number per field according to the number limits of Table 2 and the width limits of Table 1. In both cases, a general description of their composition must be provided to avoid confusion. Because they are sulfides with a D-type morphology, they may be referred to as D_S.

12.1.9 Complex inclusions, such as oxysulfides or duplex inclusions, are also rated according to their morphology: whether they are stringered or elongated (for aspect ratios ≥5) or isolated (not part of a stringer and aspect ratio <5); and then by thickness. Isolated, globular particles are rated as D-types by their average thickness. Complex Ds may be predominantly (>50 % by area) sulfides or oxides and should be identified as such. For example, if the oxide area is greater in a globular oxysulfide, it could be called a D_{OS} type. Stringered complex particles are rated by the aspect ratio of the individual particles; if <5, they are B-types, if ≥5, they are A- or C-types (separate by gray level). For those complex inclusions with aspect ratios ≥5, they are classified as A-types if more than 50 % of the area is sulfide and C-types if more than 50 % of the area is oxide. Report the composition, in general terms, to avoid confusion, and state the nature of the inclusions, for example, "globular calcium aluminates encapsulated with a thin film of calcium-manganese sulfide," or "irregular aluminates partially or fully embedded in manganese sulfide stringers."

12.2 After classification by type and thickness, the severity levels are determined for the inclusions within 0.50 mm^2 test areas based upon the total Type A sulfide lengths per field, the total Type B or C stringer lengths per field, and the number of isolated D-type inclusions per field. These values can be reported according to the length or number in each 0.50-mm^2 field or as the length per unit area or number per unit area (mm^2), but the measurements must be made on contiguous 0.50 mm^2 test areas. Severities are calculated based on the limits given in Table 2. Note that these values are the minimum length or number for each class. In general, severity values (calculated as described below) are rounded downward to the nearest whole or half unit (finer increments can be used to provide improved discrimination for steels with very low inclusion contents, see 4.4).

12.2.1 Severity values are not determined for inclusions classified as oversized according to their width. Instead, the length of the oversized Type A sulfide, the stringer length of the oversized Type B or C, or the number of the oversized Type D inclusions are reported as a separate item, along with their width or diameter.

12.2.2 If the length of an individual Type A sulfide inclusion, or the length of an individual Type B or C stringer, is greater than the standard 0.50-mm^2 field width (707 µm), it should be measured, if the image analyzer can track inclusions or stringers across contiguous fields. The total length (and width category) is reported separately as an oversized (by length) inclusion or stringer (that is, report the type, its width (thin or thick) and its length). That portion of the oversized inclusion or stringer within each field, unless it is oversized by width, is also included in the field severity determination.

12.3 Calculation of the severity number for Type A inclusions is based on a log-log plot of the data in Table 2 (Table 1 on Minimum Values for Inclusion Rating Numbers (Methods A and D) of Practice E 45). Such a plot[7] reveals a linear relationship between the severity numbers and the minimum total sulfide length per 0.50-mm^2 field for each severity level as shown in Fig. 1. A least-square fit to the data in Table 2 has been used to produce the relationships, Table 3, which can be used to calculate the severity of Type A inclusions, either thin

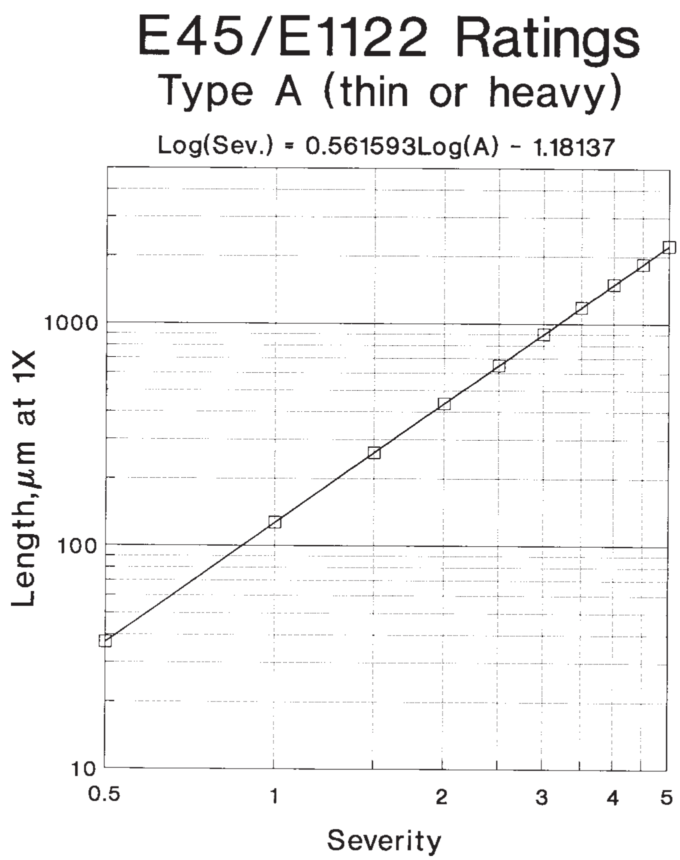

FIG. 1 Relationship Between Severity Rating and the Minimum Total Sulfide Length for Plates I and III of Practice E 45

[7] Vander Voort, G. F., and Golden, J. F., "Automating the JK Inclusion Analysis," *Microstructural Science*, Vol 10, Elsevier Science Publishing Co., Inc., NY, 1982, pp. 277–290.

or thick. The antilog is determined and rounded downward to the nearest half-severity value.

12.4 Calculation of the severity numbers for Type B and C inclusions is done in the same manner as for the Type A inclusions. Fig. 2 and Fig. 3 show log-log plots of the data from Table 2 for Type B and C inclusions, respectively. B and C severities are based on the total stringer length per field. The severities for B- or C-type inclusions are calculated using the least-square fit equations given in Table 3. These equations are based upon the data in Table 2. The antilog is computed and rounded down to the nearest half-severity level.

12.5 Calculation of the severity numbers for D-type oxides is done in the same manner as for Types A, B, and C inclusions except that the criterion is the number of oxides rather than their length. Fig. 4 shows a log-log plot of the data in Table 2. The severity of the D-type oxides is calculated using the least-square fit equations listed in Table 3. These equations are based upon the data in Table 2. The antilog is computed and rounded down to the nearest half-severity level.

12.6 An array is established in the computer memory to tabulate the number of fields that were rated according to the thin or thick limits of the four inclusion types for eleven possible severities from 0 to 5 in. half-level increments. After each field is rated and the severities are computed, the appropriate array locations are incremented to store the results.

12.7 If producer-purchaser agreements limit the analysis to only certain inclusion types, thickness categories, or severity limits, the scheme in 12.6 can be modified to analyze, measure, and store only the data of interest.

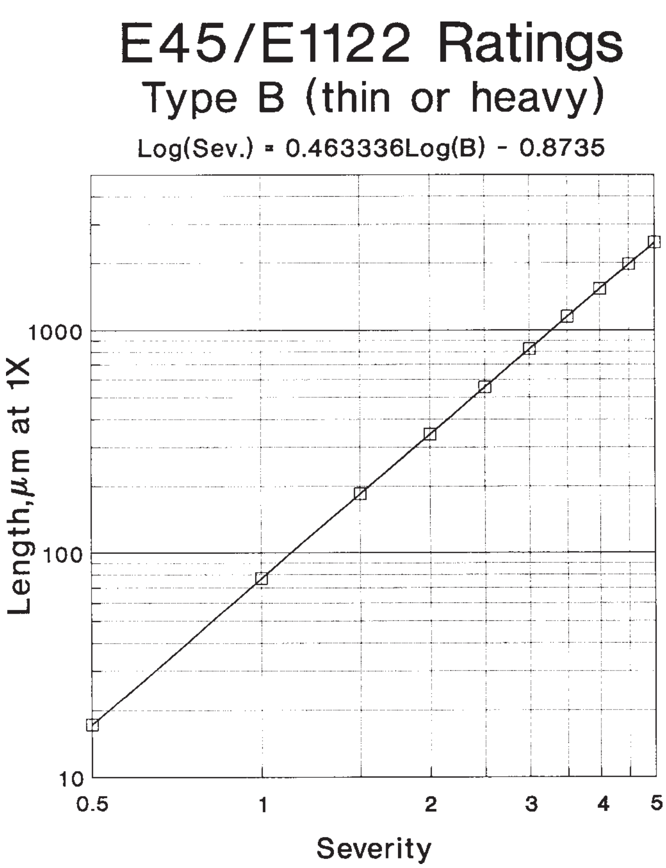

FIG. 2 Relationship Between Severity Rating and the Minimum Total B-Type Stringer Length for Plates I and III of Practice E 45

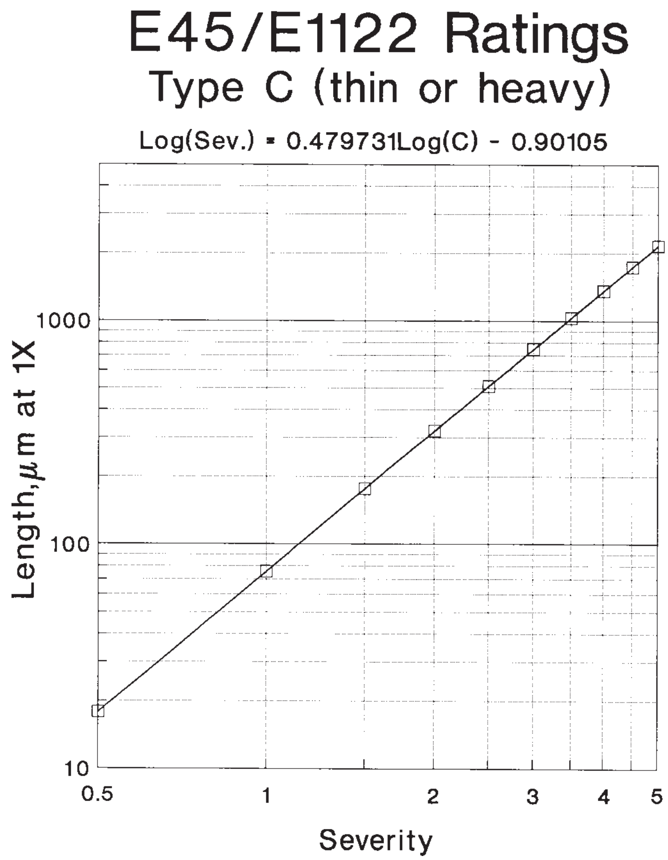

FIG. 3 Relationship Between Severity Rating and the Minimum Total C-Type Stringer Length for Plates I and III of Practice E 45

12.8 The use of randomly selected, contiguously aligned fields may not produce true worst field (Method A of Practice E 45) ratings. Valid worst field ratings require advanced image analysis technology, for example, use of a 0.50-mm^2 mask that can be moved anywhere within the 160-mm^2 test area using an algorithm that controls the mask movement by maximizing the severity values.

12.9 For quantitative inclusion descriptions, blank fields (that is, those that contain no visible inclusions of a particular type and width) may be differentiated from non-ratable fields (that is, fields with inclusions ≤ 2 µm in width, or with inclusion lengths or stringer lengths below the minimum limit for 0.5 severity).

13. Test Report

13.1 Pertinent data regarding the identity of the specimen analyzed should be reported.

13.2 The number of fields of each inclusion type (A, B, C, and D) and thickness (thin and thick) are reported for each severity from 0 to 5 in whole or half-severity level increments. For steels with very low inclusion contents, severities may be computed to one-quarter or one-tenth severity level increments. Note that for D-type inclusions, because one inclusion per field is a severity of 0.5, by definition, there can be no D-severity levels between 0 and 0.5.

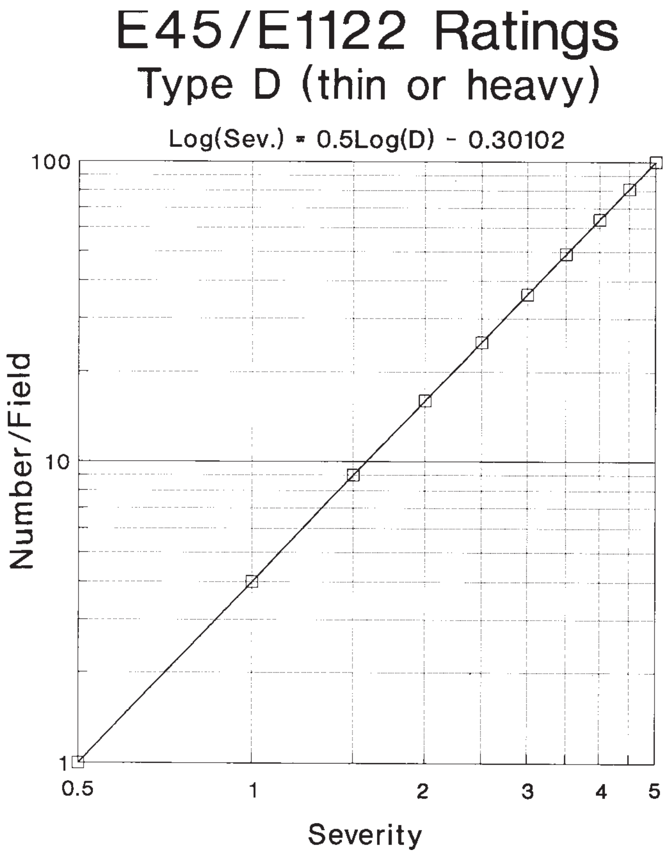

FIG. 4 Relationship Between Severity Rating and the Minimum Number of Globular D-Type Inclusions for Plates I and III of Practice E 45

13.3 If desired, based on producer-purchaser agreements, modifications of the reported data may be made, for example, reports for only certain inclusion types, thicknesses, or severity values. Other modifications may include only worst-field severity ratings or the number of fields at the worst-field severity ratings.

13.4 If desired by producer-purchaser agreement, an index may be calculated to describe the inclusion content.

13.5 To produce average results for more than one specimen per lot, the average number of fields for each severity rating, inclusion type, and thickness may be calculated as recommended by Practice E 45 (Table 4 on Example of Inclusion Rating (Method D)).

13.6 Data for inclusions or stringers that are oversized in either length or width, or both, should be reported separately. Report the inclusion type, measured width, and length (for Types A, B, and C).

13.7 Fields with zero severity levels may be further classified, if desired, as either blank (no inclusions of a particular type and width category are present) or non-ratable (inclusions are present but their length is below the 0.5 severity limit or their width is <2 μm), or their diameter is <3 μm.

13.8 Information pertaining to the composition of the inclusions (Types A to D) may be provided if desired. For rare earth- or calcium-treated steels, or other steels with nontraditional deoxidation approaches, the chemical composition of the inclusions, in general terms, must be reported with each rating. Microanalytical techniques may be required to obtain such information if the operator is not able to identify the inclusions by light optical examination.

13.9 Supplementary stereological data determined during analysis may be included in the test report as desired. Standardization of such test data is not governed by this practice (see Practice E 1245).

14. Precision and Bias

14.1 When the same specimen is reanalyzed immediately, starting over at the same location and remeasuring the same fields, reproducibility is extremely good. Worst-field ratings are usually identical, but may occasionally show a variation of one-half severity limit for one of the eight possible ratings (A to D, thin and thick). The number of fields at each severity level for each inclusion type and thickness generally varies by less than 5 %.

14.2 If a rated specimen is repolished and rated again on a parallel plane by the same laboratory, the results will be reasonably reproducible. Worst-field ratings will usually vary by no more than one-half severity level for several of the inclusion types and thickness categories but larger variations are occasionally encountered due to the inherent variability of the inclusion content.

14.3 Interlaboratory test variability has not been evaluated but may be expected to be greater. This variability will be at a minimum if each laboratory controls specimen preparation according to the guidelines in Practice E 768.

14.4 Use of a manually operated stage, rather than an automated stage, may introduce bias into the field selection.

15. Keywords

15.1 automatic image analysis; complex inclusions; globular inclusions; inclusion stringers; inclusions; JK inclusion ratings; light microscopy; metallography; oxides; steel; sulfides