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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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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.

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 Methods of Preparation of Metallographic Specimens[2]

E 7 Terminology Relating to Metallography[2]

E 45 Practice 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 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 Param-

[1] This practice is under the jurisdiction of ASTM Committee E-4 on Metallography and is the direct responsibility of Subcommittee E04.14 on Quantitative Metallography.

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[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.

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

eters (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.

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

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.

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 categeorizes 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 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

[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.

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 ± 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 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.

[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.