Designation: ~~E112 – 12~~ E112 – 13

Standard Test Methods for Determining Average Grain Size[1]

This standard is issued under the fixed designation E112; 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 U.S. Department of Defense.

INTRODUCTION

These test methods of determination of average grain size in metallic materials are primarily measuring procedures and, because of their purely geometric basis, are independent of the metal or alloy concerned. In fact, the basic procedures may also be used for the estimation of average grain, crystal, or cell size in nonmetallic materials. The comparison method may be used if the structure of the material approaches the appearance of one of the standard comparison charts. The intercept and planimetric methods are always applicable for determining average grain size. However, the comparison charts cannot be used for measurement of individual grains.

1. Scope

1.1 These test methods cover the measurement of average grain size and include the comparison procedure, the planimetric (or Jeffries) procedure, and the intercept procedures. These test methods may also be applied to nonmetallic materials with structures having appearances similar to those of the metallic structures shown in the comparison charts. These test methods apply chiefly to single phase grain structures but they can be applied to determine the average size of a particular type of grain structure in a multiphase or multiconstituent specimen.

1.2 These test methods are used to determine the average grain size of specimens with a unimodal distribution of grain areas, diameters, or intercept lengths. These distributions are approximately log normal. These test methods do not cover methods to characterize the nature of these distributions. Characterization of grain size in specimens with duplex grain size distributions is described in Test Methods E1181. Measurement of individual, very coarse grains in a fine grained matrix is described in Test Methods E930.

1.3 These test methods deal only with determination of planar grain size, that is, characterization of the two-dimensional grain sections revealed by the sectioning plane. Determination of spatial grain size, that is, measurement of the size of the three-dimensional grains in the specimen volume, is beyond the scope of these test methods.

1.4 These test methods describe techniques performed manually using either a standard series of graded chart images for the comparison method or simple templates for the manual counting methods. Utilization of semi-automatic digitizing tablets or automatic image analyzers to measure grain size is described in Test Methods E1382.

1.5 These test methods deal only with the recommended test methods and nothing in them should be construed as defining or establishing limits of acceptability or fitness of purpose of the materials tested.

1.6 The measured values are stated in SI units, which are regarded as standard. Equivalent inch-pound values, when listed, are in parentheses and may be approximate.

1.7 *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.*

1.8 The paragraphs appear in the following order:

Section	Number
Scope	1

[1] These test methods are under the jurisdiction of ASTM Committee E04 on Metallography and are the direct responsibility of Subcommittee E04.08 on Grain Size.

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2. Referenced Documents

2.1 *ASTM Standards:*[2]

E3 Guide for Preparation of Metallographic Specimens
E7 Terminology Relating to Metallography
E407 Practice for Microetching Metals and Alloys
E562 Test Method for Determining Volume Fraction by Systematic Manual Point Count
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
E883 Guide for Reflected–Light Photomicrography
E930 Test Methods for Estimating the Largest Grain Observed in a Metallographic Section (ALA Grain Size)
E1181 Test Methods for Characterizing Duplex Grain Sizes
E1382 Test Methods for Determining Average Grain Size Using Semiautomatic and Automatic Image Analysis

2.2 *ASTM Adjuncts:*

2.2.1 For a complete adjunct list, see Appendix X2

3. Terminology

3.1 *Definitions*—For definitions of terms used in these test methods, see Terminology E7.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *ASTM grain size number*—the ASTM grain size number, G, was originally defined as:

$$N_{AE} = 2^{G-1} \tag{1}$$

where N_{AE} is the number of grains per square inch at 100X magnification. To obtain the number per square millimetre at 1X, multiply by 15.50.

3.2.2 *grain*—an individual crystal with the same atomic configuration throughout in a polycrystalline material; the grain may or may not contain twinned regions within it or sub-grains.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.2.3 ~~*grain*—~~*grain boundary—*~~that area within the confines of the original (primary) boundary observed on the two-dimensional plane-of-polish or that volume enclosed by the original (primary) boundary in the three-dimensional object. In materials containing twin boundaries, the twin boundaries are ignored, that is, the structure on either side of a twin boundary belongs to the grain.~~ a very narrow region in a polycrystalline material corresponding to the transition from one crystallographic orientation to another, thus separating one adjacent grain from another; on a two-dimensional plane through three-dimensional polycrystalline materials, the grain edges between adjacent grains surrounding a single grain make up the outline of the two-dimensional grains that are observed in the light microscope and are measured or counted by the procedures in this test method.

3.2.4 *grain boundary intersection* ~~*count*—~~*count, P—*determination of the number of times a test line cuts across, or is tangent ~~to,~~ to (tangent hits are counted as one (1) intersection) grain boundaries (triple point intersections are considered as 1-½ intersections).

3.2.5 *grain intercept* ~~*count*—~~*count, N—*determination of the number of times a test line cuts through individual grains on the plane of polish (tangent hits are considered as one half an interception; test lines that end within a grain are considered as one half an interception).

3.2.6 *intercept length*—the distance between two opposed, adjacent grain boundary intersection points on a test line segment that crosses the grain at any location due to random placement of the test line.

3.3 *Symbols:*

α	=	matrix grains in a two phase (constituent) microstructure.
A	=	test area.
$\bar{A}$	=	mean grain cross sectional area.
AI_ℓ	=	grain elongation ratio or anisotropy index for a longitudinally oriented plane.
$\bar{d}$	=	mean planar grain diameter (Plate III).
$\bar{D}$	=	mean spatial (volumetric) grain diameter.
f	=	Jeffries multiplier for planimetric method.
G	=	ASTM grain size number.
$\bar{\ell}$	=	mean lineal intercept length.
$\bar{\ell}_\alpha$	=	mean lineal intercept length of the α matrix phase in a two phase (constituent) microstructure.
$\bar{\ell}_\ell$	=	mean lineal intercept length on a longitudinally oriented surface for a non-equiaxed grain structure.
$\bar{\ell}_t$	=	mean lineal intercept length on a transversely oriented surface for a non-equiaxed grain structure.
$\bar{\ell}_p$	=	mean lineal intercept length on a planar oriented surface for a non-equiaxed grain structure.
ℓ_0	=	base intercept length of 32.00 mm for defining the relationship between G and ℓ (and N_L) for macroscopically or microscopically determined grain size by the intercept method.
L	=	length of a test line.
M	=	magnification used.
M_b	=	magnification used by a chart picture series.
n	=	number of fields measured.
N_α	=	number of α grains intercepted by the test line in a two phase (constituent) microstructure.
N_A	=	number of grains per mm^2 at 1X.
$N_{A\alpha}$	=	number of α grains per mm^2 at 1X in a two phase (constituent) microstructure.
N_{AE}	=	number of grains per inch^2 at 100X.
$N_{A\ell}$	=	N_A on a longitudinally oriented surface for a non-equiaxed grain structure.
N_{At}	=	N_A on a transversely oriented surface for a non-equiaxed grain structure.
N_{Ap}	=	N_A on a planar oriented surface for a non-equiaxed grain structure.
N_I	=	number of intercepts with a test line.
N_{Inside}	=	number of grains completely within a test circle.
$N_{\text{Intercepted}}$	=	number of grains intercepted by the test circle.
N_L	=	number of intercepts per unit length of test line.
$N_{L\ell}$	=	N_L on a longitudinally oriented surface for a non-equiaxed grain structure.
N_{Lt}	=	N_L on a transversely oriented surface for a non-equiaxed grain structure.
N_{Lp}	=	N_L on a planar oriented surface for a non-equiaxed grain structure.
P_I	=	number of grain boundary intersections with a test line.
P_L	=	number of grain boundary intersections per unit length of test line.
$P_{L\ell}$	=	P_L on a longitudinally oriented surface for a non-equiaxed grain structure.
P_{Lt}	=	P_L on a transversely oriented surface for a non-equiaxed grain structure.
P_{Lp}	=	P_L on a planar oriented surface for a non-equiaxed grain structure.
Q	=	correction factor for comparison chart ratings using a non-standard magnification for microscopically determined grain sizes.
Q_m	=	correction factor for comparison chart ratings using a non-standard magnification for macroscopically determined grain sizes.
s	=	standard deviation.

S_V = grain boundary surface area to volume ratio for a single phase structure.
$S_{V\alpha}$ = grain boundary surface area to volume ratio for a two phase (constituent) structure.
t = students' t multiplier for determination of the confidence interval.
$V_{V\alpha}$ = volume fraction of the α phase in a two phase (constituent) microstructure.
95 %CI = 95 % confidence interval.
%RA = percent relative accuracy.

4. Significance and Use

4.1 These test methods cover procedures for estimating and rules for expressing the average grain size of all metals consisting entirely, or principally, of a single phase. The grain size of specimens with two phases, or a phase and a constituent, can be measured using a combination of two methods, a measurement of the volume fraction of the phase and an intercept or planimetric count (see Section 17). The test methods may also be used for any structures having appearances similar to those of the metallic structures shown in the comparison charts. The three basic procedures for grain size estimation are:

4.1.1 *Comparison Procedure*—The comparison procedure does not require counting of either grains, intercepts, or intersections but, as the name suggests, involves comparison of the grain structure to a series of graded images, either in the form of a wall chart, clear plastic overlays, or an eyepiece reticle. There appears to be a general bias in that comparison grain size ratings claim that the grain size is somewhat coarser (½ to 1 *G* number lower) than it actually is (see X1.3.5). Repeatability and reproducibility of comparison chart ratings are generally ±1 grain size number.

4.1.2 *Planimetric Procedure*—The planimetric method involves an actual count of the number of grains within a known area. The number of grains per unit area, N_A, is used to determine the ASTM grain size number, *G*. The precision of the method is a function of the number of grains counted. A precision of ±0.25 grain size units can be attained with a reasonable amount of effort. Results are free of bias and repeatability and reproducibility are less than ±0.5 grain size units. An accurate count does require marking off of the grains as they are counted.

4.1.3 *Intercept Procedure*—The intercept method involves an actual count of the number of grains intercepted by a test line or the number of grain boundary intersections with a test line, per unit length of test line, used to calculate the mean lineal intercept length, $\bar{\ell}$. $\bar{\ell}$ is used to determine the ASTM grain size number, *G*. The precision of the method is a function of the number of intercepts or intersections counted. A precision of better than ±0.25 grain size units can be attained with a reasonable amount of effort. Results are free of bias; repeatability and reproducibility are less than ±0.5 grain size units. Because an accurate count can be made without need of marking off intercepts or intersections, the intercept method is faster than the planimetric method for the same level of precision.

4.2 For specimens consisting of equiaxed grains, the method of comparing the specimen with a standard chart is most convenient and is sufficiently accurate for most commercial purposes. For higher degrees of accuracy in determining average grain size, the intercept or planimetric procedures may be used. The intercept procedure is particularly useful for structures consisting of elongated ~~grains.~~grains (see Section 16).

4.3 In case of dispute, the ~~intercept~~planimetric procedure shall be the referee procedure in all cases.

4.4 No attempt should be made to estimate the average grain size of heavily cold-worked material. Partially recrystallized wrought alloys and lightly to moderately cold-worked material may be considered as consisting of non-equiaxed grains, if a grain size measurement is necessary.

4.5 *Individual grain measurements should not be made based on the standard comparison charts.* These charts were constructed to reflect the typical log-normal distribution of grain sizes that result when a plane is passed through a three-dimensional array of grains. Because they show a distribution of grain dimensions, ranging from very small to very large, depending on the relationship of the planar section and the three-dimensional array of grains, the charts are not applicable to measurement of individual grains.

5. Generalities of Application

5.1 It is important, in using these test methods, to recognize that the ~~estimation~~measurement of average grain size is not ~~a precise~~an exact measurement. A metal structure is an aggregate of three-dimensional crystals of varying sizes and shapes. Even if all these crystals were identical in size and shape, the grain cross sections, produced by a random plane (surface of observation) through such a structure, would have a distribution of areas varying from a maximum value to zero, depending upon where the plane cuts each individual crystal. Clearly, no two fields of observation can be exactly the same.

5.2 The size and location of grains in a microstructure are normally completely random. No nominally random process of positioning a test pattern can improve this randomness, but random processes can yield poor representation by concentrating measurements in part of a specimen. *Representative* implies that all parts of the specimen contribute to the result, not, as sometimes has been presumed, that fields of average grain size are selected. Visual selection of fields, or casting out of extreme measurements, may not falsify the average when done by unbiased experts, but will in all cases give a false impression of high precision. For representative sampling, the area of the specimen is mentally divided into several equal coherent sub-areas and stage positions prespecified, which are approximately at the center of each sub-area. The stage is successively set to each of these positions and the test pattern applied blindly, that is, with the light out, the shutter closed, or the eye turned away. No touch-up of the position so selected is allowable. Only measurements made on fields chosen in this way can be validated with respect to precision and bias.

6. Sampling

6.1 Specimens should be selected to represent average conditions within a heat lot, treatment lot, or product, or to assess variations anticipated across or along a product or component, depending on the nature of the material being tested and the purpose of the study. Sampling location and frequency should be based upon agreements between the manufacturers and the users.

6.2 Specimens should not be taken from areas affected by shearing, burning, or other processes that will alter the grain structure.

7. Test Specimens

7.1 In general, if the grain structure is equiaxed, any specimen orientation is acceptable. However, the presence of an equiaxed grain structure in a wrought specimen can only be determined by examination of a plane of polish parallel to the deformation axis.

7.2 If the grain structure on a ~~longitudinally oriented~~ longitudinally-oriented specimen is equiaxed, then grain size measurements on this plane, or any other, will be equivalent within the statistical precision of the test method. If the grain structure is not equiaxed, but elongated, then grain size measurements on specimens with different orientations will vary. In this case, the grain size should be evaluated on at least two of the three principle planes, transverse, longitudinal, and planar (or radial and transverse for round bar) and averaged as described in Section 16 to obtain the mean grain size. If directed test lines are used, rather than test circles, intercept counts on non-equiaxed grains in plate or sheet type specimens can be made using only two principle test planes, rather than all three as required for the planimetric method.

7.3 The surface to be polished should be large enough in area to permit measurement of at least five fields at the desired magnification. In most cases, except for thin sheet or wire specimens, a minimum polished surface area of 160 mm^2 (0.25 $in.^2$) is adequate.

7.4 The specimen shall be sectioned, mounted (if necessary), ground, and polished according to the recommended procedures in Practice E3. The specimen shall be etched using a reagent, such as listed in Practice E407, to delineate most, or all, of the grain boundaries (see also Annex A3).

TABLE 1 Suggested Comparison Charts for Metallic Materials

NOTE 1—These suggestions are based upon the customary practices in industry. For specimens prepared according to special techniques, the appropriate comparison standards should be selected on a structural-appearance basis in accordance with 8.2.

Material	Plate Number	Basic Magnification
Aluminum	I	100X
Copper and copper-base alloys (see Annex A4)	III or IV	75X, 100X
Iron and steel:		
Austenitic	II or IV	100X
Ferritic	I	100X
Carburized	IV	100X
Stainless	II	100X
Magnesium and magnesium-base alloys	I or II	100X
Nickel and nickel-base alloys	II	100X
Super-strength alloys	I or II	100X
Zinc and zinc-base alloys	I or II	100X

8. Calibration

8.1 Use a stage micrometer to determine the true linear magnification for each objective, eyepiece and bellows, or zoom setting to be used within ±2 %.

8.2 Use a ruler with a millimetre scale to determine the actual length of straight test lines or the diameter of test circles used as grids.

9. Preparation of Photomicrographs

9.1 When photomicrographs are used for estimating the average grain size, they shall be prepared in accordance with Guide E883.

10. Comparison Procedure

10.1 The comparison procedure shall apply to completely recrystallized ~~or cast~~ materials with equiaxed grains.

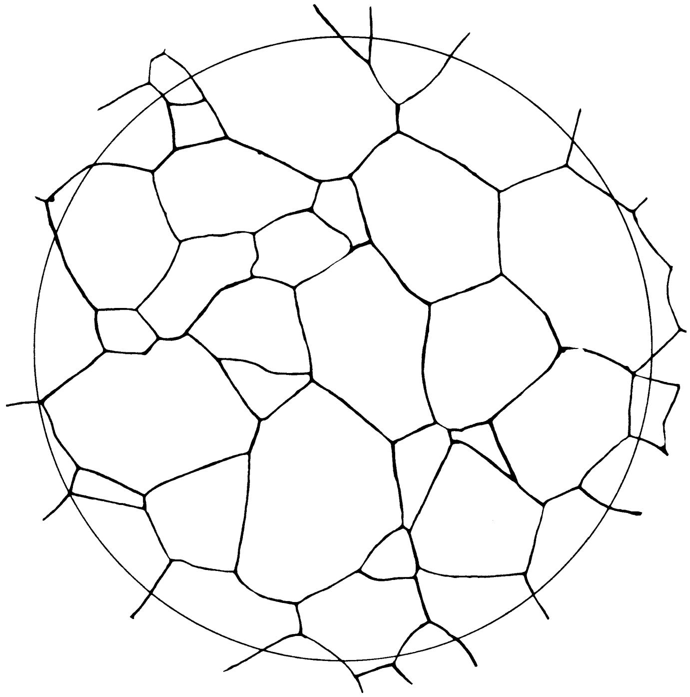

FIG. 1 Example of Untwinned Grains (Flat Etch) from Plate I. Grain Size No. 3 at 100X

10.2 When grain size estimations are made by the more convenient comparison method, repeated checks by individuals as well as by interlaboratory tests have shown that unless the appearance of the standard reasonably well approaches that of the sample, errors may occur. To minimize such errors, the comparison charts are presented in four categories as follows:[3]

10.2.1 *Plate I*—Untwinned grains (flat etch). Includes grain size numbers 00, 0, ½, 1, 1½, 2, 2½, 3, 3½, 4, 4½, 5, 5½, 6, 6½, 7, 7½, 8, 8½, 9, 9½, 10, at 100X.

10.2.2 *Plate II*—Twinned grains (flat etch). Includes grain size numbers, 1, 2, 3, 4, 5, 6, 7, 8, at 100X.

10.2.3 *Plate III*—Twinned grains (contrast etch). Includes nominal grain diameters of 0.200, 0.150, 0.120, 0.090, 0.070, 0.060, 0.050, 0.045, 0.035, 0.025, 0.020, 0.015, 0.010, 0.005 mm at 75X.

10.2.4 *Plate IV*—Austenite grains in steel (McQuaid-Ehn). Includes grain size numbers 1, 2, 3, 4, 5, 6, 7, 8, at 100X.

10.3 Table 1 lists a number of materials and the comparison charts that are suggested for use in estimating their average grain sizes. For example, for twinned copper and brass with a contrast etch, use Plate III.

NOTE 1—Examples of grain-size standards from Plates I, II, III, and IV are shown in Fig. 1, Fig. 2, Fig. 3, and Fig. 4.

10.4 The estimation of microscopically-determined grain size should usually be made by direct comparison at the same magnification as the appropriate chart. Accomplish this by comparing a projected image or a photomicrograph of a representative field of the test specimen with the photomicrographs of the appropriate standard grain-size series, or with suitable reproductions or transparencies of them, and select the photomicrograph which most nearly matches the image of the test specimen or interpolate between two standards. Report this estimated grain size as the ASTM grain size number, or grain diameter, of the chart picture that most closely matches the image of the test specimen or as an interpolated value between two standard chart pictures.

10.5 Good judgment on the part of the observer is necessary to select the magnification to be used, the proper size of area (number of grains), and the number and location in the specimen of representative sections and fields for estimating the characteristic or average grain size. It is not sufficient to visually select what appear to be areas of average grain size. Recommendations for choosing appropriate areas for all procedures have been noted in 5.2.

10.6 Grain size estimations shall be made on three or more representative areas of each specimen section.

10.7 When the grains are of a size outside the range covered by the standard photographs, or when magnifications of 75X or 100X are not satisfactory, other magnifications may be employed for comparison by using the relationships given in Note 2 and Table 2. It may be noted that alternative magnifications are usually simple multiples of the basic magnifications.

NOTE 2—If the grain size is reported in ASTM numbers, it is convenient to use the relationship:

[3] Plates I, II, III, and IV are available from ASTM Headquarters. Order Adjunct: ADJE11201P (Plate I), ADJE11202P (Plate II), ADJE11203P (Plate III), and ADJE11204P (Plate IV). A combination of all four plates is also available. Order Adjunct: ADJE112PS.

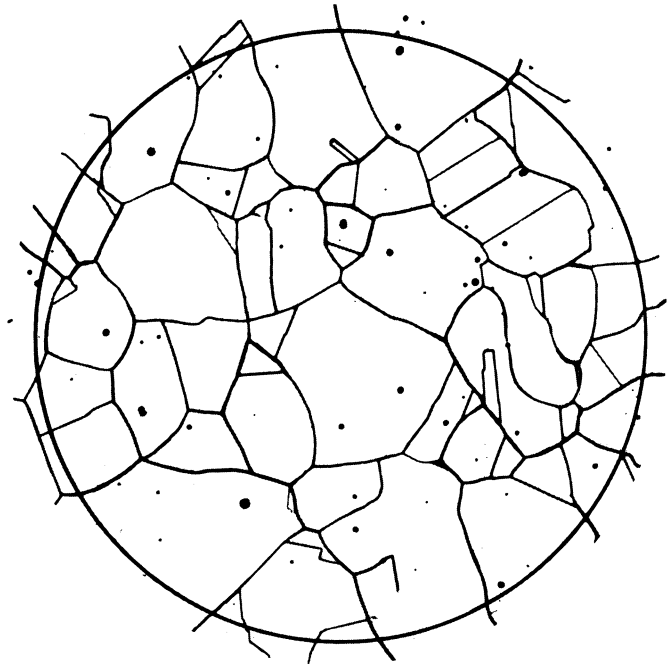

FIG. 2 Example of Twin Grains (Flat Etch) from Plate II. Grain Size No. 3 at 100X

FIG. 3 Example of Twin Grains (Contrast Etch) from Plate III. Grain Size 0.090 mm at 75X

$$Q = 2 \log_2 (M/M_b) \tag{2}$$

$$= 6.64 \log_{10} (M/M_b)$$

where Q is a correction factor that is added to the apparent micro-grain size of the specimen, as viewed at the magnification, M, instead of at the basic magnification, M_b (75X or 100X), to yield the true ASTM grain-size number. Thus, for a magnification of 25X, the true ASTM grain-size number is four numbers lower than that of the corresponding photomicrograph at 100X ($Q = -4$). Likewise, for 400X, the true ASTM grain-size number is four numbers higher ($Q = +4$) than that of the corresponding photomicrograph at 100X. Similarly, for 300X, the true ASTM grain-size number is four numbers higher than that of the corresponding photomicrograph at 75X.

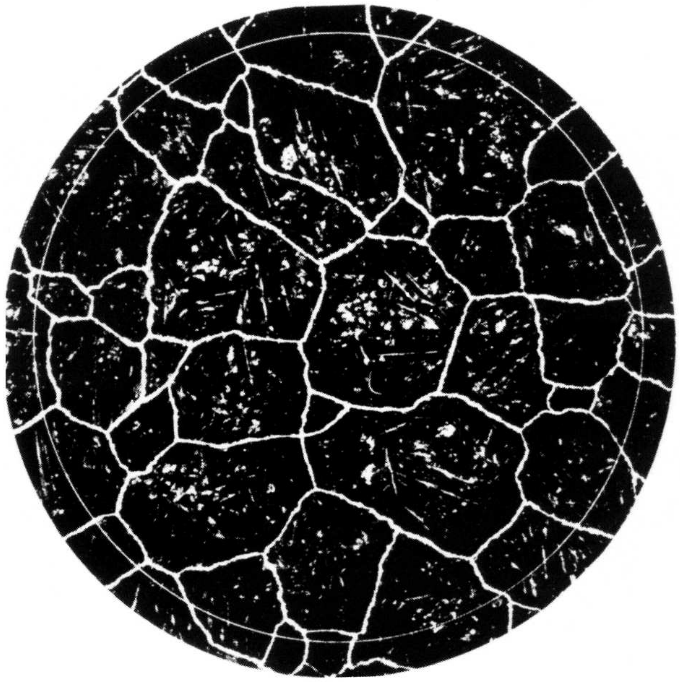

FIG. 4 Example of Austenite Grains in Steel from Plate IV. Grain Size No. 3 at 100X

TABLE 2 Microscopically Determined Grain Size Relationships Using Plate III at Various Magnifications

NOTE 1—First line—mean grain diameter, d, in mm; in parentheses—equivalent ASTM grain size number, G.

NOTE 2—Magnification for Plate III is 75X (row 3 data).

Magnification	Chart Picture Number (Plate III)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
25X	0.015 (9.2)	0.030 (7.2)	0.045 (6.0)	0.060 (5.2)	0.075 (4.5)	0.105 (3.6)	0.135 (2.8)	0.150 (2.5)	0.180 (2.0)	0.210 (1.6)	0.270 (0.8)	0.360 (0)	0.451 (0/00)	0.600 (00 +)
50X	0.0075 (11.2)	0.015 (9.2)	0.0225 (8.0)	0.030 (7.2)	0.0375 (6.5)	0.053 (5.6)	0.0675 (4.8)	0.075 (4.5)	0.090 (4.0)	0.105 (3.6)	0.135 (2.8)	0.180 (2.0)	0.225 (1.4)	0.300 (0.5)
75X	0.005 (12.3)	0.010 (10.3)	0.015 (9.2)	0.020 (8.3)	0.025 (7.7)	0.035 (6.7)	0.045 (6.0)	0.050 (5.7)	0.060 (5.2)	0.070 (4.7)	0.090 (4.0)	0.120 (3.2)	0.150 (2.5)	0.200 (1.7)
100X	0.00375 (13.2)	0.0075 (11.2)	0.0112 (10.0)	0.015 (9.2)	0.019 (8.5)	0.026 (7.6)	0.034 (6.8)	0.0375 (6.5)	0.045 (6.0)	0.053 (5.6)	0.067 (4.8)	0.090 (4.0)	0.113 (3.4)	0.150 (2.5)
200X	0.0019 (15.2)	0.00375 (13.2)	0.0056 (12.0)	0.0075 (11.2)	0.009 (10.5)	0.013 (9.6)	0.017 (8.8)	0.019 (8.5)	0.0225 (8.0)	0.026 (7.6)	0.034 (6.8)	0.045 (6.0)	0.056 (5.4)	0.075 (4.5)
400X	—	0.0019 (15.1)	0.0028 (14.0)	0.0038 (13.1)	0.0047 (12.5)	0.0067 (11.5)	0.0084 (10.8)	0.009 (10.5)	0.0012 (10.0)	0.0133 (9.5)	0.0168 (8.8)	0.0225 (8.0)	0.028 (7.3)	0.0375 (6.5)
500X	—	—	0.0022 (14.6)	0.003 (13.7)	0.00375 (13.1)	0.00525 (12.1)	0.0067 (11.5)	0.0075 (11.1)	0.009 (10.6)	0.010 (10.3)	0.0133 (9.5)	0.018 (8.7)	0.0225 (8.0)	0.03 (7.1)

10.8 The small number of grains per field at the coarse end of the chart series, that is, size 00, and the very small size of the grains at the fine end make accurate comparison ratings difficult. When the specimen grain size falls at either end of the chart range, a more meaningful comparison can be made by changing the magnification so that the grain size lies closer to the center of the range.

10.9 The use of transparencies[4] or prints of the standards, with the standard and the unknown placed adjacent to each other, is to be preferred to the use of wall chart comparison with the projected image on the microscope screen.

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[4] Transparencies of the various grain sizes in Plate I are available from ASTM Headquarters. Order Adjunct: ADJE112TS for the set. Transparencies of individual grain size groupings are available on request. Order Adjunct: ADJE11205T (Grain Size 00), ADJE11206T (Grain Size 0), ADJE11207T (Grain Size 0.5), ADJE11208T (Grain Size 1.0), ADJE11209T (Grain Size 1.5), ADJE11210T (Grain Size 2.0), ADJE11211T (Grain Size 2.5), ADJE11212T (Grain Sizes 3.0, 3.5, and 4.0), ADJE11213T (Grain Sizes 4.5, 5.0, and 5.5), ADJE11214T (Grain Sizes 6.0, 6.5, and 7.0), ADJE11215T (Grain Sizes 7.5, 8.0, and 8.5), and ADJE11216T (Grain Sizes 9.0, 9.5, and 10.0). Charts illustrating grain size numbers 00 to 10 are on 8½ by 11 in. (215.9 by 279.4 mm) film. Transparencies for Plates II, III, and IV are not available.

TABLE 3 Macroscopic Grain Size Relationships Computed for Uniform, Randomly Oriented, Equiaxed Grains

NOTE 1—Macroscopically determined grain size numbers M-12.3, M-13.3, M-13.8 and M-14.3 correspond, respectively, to microscopically determined grain size numbers (*G*) 00, 0, 0.5 and 1.0.

Macro Grain Size No.	$\bar{N}_A$ Grains/Unit Area		$\bar{A}$ Average Grain Area		$\bar{d}$ Average Diameter		$\bar{\ell}$ Mean Intercept		$\bar{N}_L$	$\bar{N}$
	No./mm²	No./in.²	mm²	in.²	mm	in.	mm	in.	mm⁻¹	100 mm
M-0	0.0008	0.50	1290.3	2.00	35.9	1.41	32.00	1.2	0.031	3.13
M-0.5	0.0011	0.71	912.4	1.41	30.2	1.19	26.91	1.0	0.037	3.72
M-1.0	0.0016	1.00	645.2	1.00	25.4	1.00	22.63	0.89	0.044	4.42
M-1.5	0.0022	1.41	456.2	0.707	21.4	0.841	19.03	0.74	0.053	5.26
M-2.0	0.0031	2.00	322.6	0.500	18.0	0.707	16.00	0.63	0.063	6.25
M-2.5	0.0044	2.83	228.1	0.354	15.1	0.595	13.45	0.53	0.074	7.43
M-3.0	0.0062	4.00	161.3	0.250	12.7	0.500	11.31	0.44	0.088	8.84
M-3.5	0.0088	5.66	114.0	0.177	10.7	0.420	9.51	0.37	0.105	10.51
M-4.0	0.0124	8.00	80.64	0.125	8.98	0.354	8.00	0.31	0.125	12.50
M-4.5	0.0175	11.31	57.02	0.0884	7.55	0.297	6.73	0.26	0.149	14.87
M-5.0	0.0248	16.00	40.32	0.0625	6.35	0.250	5.66	0.22	0.177	17.68
M-5.5	0.0351	22.63	28.51	0.0442	5.34	0.210	4.76	0.18	0.210	21.02
M-6.0	0.0496	32.00	20.16	0.0312	4.49	0.177	4.00	0.15	0.250	25.00
M-6.5	0.0701	45.26	14.26	0.0221	3.78	0.149	3.36	0.13	0.297	29.73
M-7.0	0.099	64.00	10.08	0.0156	3.17	0.125	2.83	0.11	0.354	35.36
M-7.5	0.140	90.51	7.13	0.0110	2.67	0.105	2.38	0.093	0.420	42.05
				$\times10^{-3}$		$\times10^{-3}$		$\times10^{-3}$		
M-8.0	0.198	128.0	5.04	7.812	2.25	88.4	2.00	78.7	0.500	50.00
M-8.5	0.281	181.0	3.56	5.524	1.89	74.3	1.68	66.2	0.595	59.46
M-9.0	0.397	256.0	2.52	3.906	1.59	62.5	1.41	55.7	0.707	70.71
M-9.5	0.561	362.1	1.78	2.762	1.33	52.6	1.19	46.8	0.841	84.09
M-10.0	0.794	512.0	1.26	1.953	1.12	44.2	1.00	39.4	1.00	100.0
M-10.5	1.122	724.1	0.891	1.381	0.994	37.2	0.841	33.1	1.19	118.9
M-11.0	1.587	1024.1	0.630	0.977	0.794	31.2	0.707	27.8	1.41	141.4
M-11.5	2.245	1448.2	0.0445	0.690	0.667	26.3	0.595	23.4	1.68	168.2
M-12.0	3.175	2048.1	0.315	0.488	0.561	22.1	0.500	19.7	2.00	200.0
M-12.3	3.908	2521.6	0.256	0.397	0.506	19.9	0.451	17.7	2.22	221.9
M-12.5	4.490	2896.5	0.223	0.345	0.472	18.6	0.420	16.6	2.38	237.8
M-13.0	6.349	4096.3	0.157	0.244	0.397	15.6	0.354	13.9	2.83	282.8
M-13.3	7.817	5043.1	0.128	0.198	0.358	14.1	0.319	12.5	3.14	313.8
M-13.5	8.979	5793.0	0.111	0.173	0.334	13.1	0.297	11.7	3.36	336.4
M-13.8	11.055	7132.1	0.091	0.140	0.301	11.8	0.268	10.5	3.73	373.2
M-14.0	12.699	8192.6	0.079	0.122	0.281	11.0	0.250	9.84	4.00	400.0
M-14.3	15.634	10086.3	0.064	0.099	0.253	9.96	0.225	8.87	4.44	443.8

10.10 No particular significance should be attached to the fact that different observers often obtain slightly different results, provided the different results fall within the confidence limits reasonably expected with the procedure used.

10.11 There is a possibility when an operator makes repeated checks on the same specimen using the comparison method that they will be prejudiced by their first estimate. This disadvantage can be overcome, when necessary, by changes in magnification, through bellows extension, or objective or eyepiece replacement between estimates (**1**).[5]

10.12 Make the estimation of macroscopically-determined grain sizes (extremely coarse) by direct comparison, at a magnification of 1X, of the properly prepared specimen, or of a photograph of a representative field of the specimen, with photographs of the standard grain series shown in Plate I (for untwinned material) and Plates II and III (for twinned material). Since the photographs of the standard grain size series were made at 75 and 100 diameters magnification, grain sizes estimated in this way do not fall in the standard ASTM grain-size series and hence, preferably, should be expressed either as diameter of the average grain or as one of the macro-grain size numbers listed in Table 3. For the smaller macroscopic grain sizes, it may be preferable to use a higher magnification and the correction factor given in Note 3, particularly if it is desirable to retain this method of reporting.

NOTE 3—If the grain size is reported in ASTM macro-grain size numbers, it is convenient to use the relationship:

$$Q_m = 2\log_2 M \quad (3)$$

$$= 6.64 \log_{10} M$$

where Q_M is a correction factor that is added to the apparent grain size of the specimen, when viewed at the magnification M, instead of at 1X, to yield the true ASTM macro-grain size number. Thus, for a magnification of 2X, the true ASTM macro-grain size number is two numbers higher ($Q = +2$), and for 4X, the true ASTM macro-grain size number is four numbers higher ($Q = +4$) than that of the corresponding photograph.

[5] The boldface numbers in parentheses refer to the list of references appended to these test methods.

TABLE 4 Grain Size Relationships Computed for Uniform, Randomly Oriented, Equiaxed Grains

Grain Size No. G	$\bar{N}_A$ Grains/Unit Area		$\bar{A}$ Average Grain Area		$\bar{d}$ Average Diameter		$\bar{\ell}$ Mean Intercept		$\bar{N}_L$
	No./in.^{2} at 100X	No./mm^2 at 1X	mm^2	μm^2	mm	μm	mm	μm	No./mm
00	0.25	3.88	0.2581	258064	0.5080	508.0	0.4525	452.5	2.21
0	0.50	7.75	0.1290	129032	0.3592	359.2	0.3200	320.0	3.12
0.5	0.71	10.96	0.0912	91239	0.3021	302.1	0.2691	269.1	3.72
1.0	1.00	15.50	0.0645	64516	0.2540	254.0	0.2263	226.3	4.42
1.5	1.41	21.92	0.0456	45620	0.2136	213.6	0.1903	190.3	5.26
2.0	2.00	31.00	0.0323	32258	0.1796	179.6	0.1600	160.0	6.25
2.5	2.83	43.84	0.0228	22810	0.1510	151.0	0.1345	134.5	7.43
3.0	4.00	62.00	0.0161	16129	0.1270	127.0	0.1131	113.1	8.84
3.5	5.66	87.68	0.0114	11405	0.1068	106.8	0.0951	95.1	10.51
4.0	8.00	124.00	0.00806	8065	0.0898	89.8	0.0800	80.0	12.50
4.5	11.31	175.36	0.00570	5703	0.0755	75.5	0.0673	67.3	14.87
5.0	16.00	248.00	0.00403	4032	0.0635	63.5	0.0566	56.6	17.68
5.5	22.63	350.73	0.00285	2851	0.0534	53.4	0.0476	47.6	21.02
6.0	32.00	496.00	0.00202	2016	0.0449	44.9	0.0400	40.0	25.00
6.5	45.25	701.45	0.00143	1426	0.0378	37.8	0.0336	33.6	29.73
7.0	64.00	992.00	0.00101	1008	0.0318	31.8	0.0283	28.3	35.36
7.5	90.51	1402.9	0.00071	713	0.0267	26.7	0.0238	23.8	42.04
8.0	128.00	1984.0	0.00050	504	0.0225	22.5	0.0200	20.0	50.00
8.5	181.02	2805.8	0.00036	356	0.0189	18.9	0.0168	16.8	59.46
9.0	256.00	3968.0	0.00025	252	0.0159	15.9	0.0141	14.1	70.71
9.5	362.04	5611.6	0.00018	178	0.0133	13.3	0.0119	11.9	84.09
10.0	512.00	7936.0	0.00013	126	0.0112	11.2	0.0100	10.0	100.0
10.5	724.08	11223.2	0.000089	89.1	0.0094	9.4	0.0084	8.4	118.9
11.0	1024.00	15872.0	0.000063	63.0	0.0079	7.9	0.0071	7.1	141.4
11.5	1448.15	22446.4	0.000045	44.6	0.0067	6.7	0.0060	5.9	168.2
12.0	2048.00	31744.1	0.000032	31.5	0.0056	5.6	0.0050	5.0	200.0
12.5	2896.31	44892.9	0.000022	22.3	0.0047	4.7	0.0042	4.2	237.8
13.0	4096.00	63488.1	0.000016	15.8	0.0040	4.0	0.0035	3.5	282.8
13.5	5792.62	89785.8	0.000011	11.1	0.0033	3.3	0.0030	3.0	336.4
14.0	8192.00	126976.3	0.000008	7.9	0.0028	2.8	0.0025	2.5	400.0

10.13 The comparison procedure shall be applicable for estimating the ~~austenite~~prior-austenite grain size in ferritic steel after a McQuaid-Ehn test (see Annex A3, A3.2), or after the ~~austenite~~prior-austenite grains have been revealed by any other means (see Annex A3, A3.3). Make the grain-size measurement by comparing the microscopic image, at magnification of 100X, with the standard grain size chart in Plate IV, for grains developed in a McQuaid-Ehn test (see Annex A3); for the measurement of ~~austenite~~prior-austenite grains developed by other means (see Annex A3), measure by comparing the microscopic image with the plate having the most nearly comparable structure observed in Plates I, II, or IV.

10.14 The ~~so-called~~ "Shepherd Fracture Grain Size Method" of judging grain size from the appearance of the fracture of a hardened tool steel (**2**), involves comparison of the specimen under investigation with a set of standard fractures.[6] It has been found that the arbitrarily numbered fracture grain size series agree well with the correspondingly numbered ASTM grain sizes presented in Table 4. This coincidence makes the fracture grain sizes interchangeable with the ~~austenitic~~prior-austenite grain sizes determined microscopically. The sizes observed microscopically shall be considered the primary standard, since they can be determined with measuring instruments.

11. Planimetric (or Jeffries') (3) Procedure

11.1 ~~In~~For the planimetric procedure, inscribe a circle ~~or rectangle~~ of known area (usually 5000 mm^2 to simplify the calculations) on a micrograph, a monitor or on the ground-glass screen of the ~~metallograph.~~ metallograph or video monitor. Select a magnification which will give at least 50 grains in the field to be counted. When the image is focused properly, count the number of grains within this area. The sum of all the grains included completely within the known area plus one half the number of grains intersected by the circumference of the area gives the number of equivalent whole grains, measured at the magnification used, within the area. If this number is multiplied by the Jeffries' multiplier, f, in the second column of Table 5 opposite the appropriate magnification, the product will be the number of grains per square millimetre N_A . Count a minimum of three fields to ensure a reasonable average. The number of grains per square millimetre at 1X, N_A , is calculated from:

$$N_A = f\left(N_{\text{Inside}} + \frac{N_{\text{Intercepted}}}{2}\right) \tag{4}$$

where f is the Jeffries' multiplier (see Table 5), N_{Inside} is the number of grains completely inside the test circle and $N_{\text{Intercepted}}$ is the number of grains that intercept the test circle. The average grain area, $\bar{A}$, is the reciprocal of N_A , that is, 1/ N_A , while the

[6] A photograph of the Shepherd standard fractures can be obtained from ASTM Headquarters. Order Adjunct: ADJE011224.

TABLE 5 Relationship Between Magnification Used and Jeffries' Multiplier, *f*, for an Area of 5000 mm² (a Circle of 79.8-mm Diameter) ($f = 0.0002M^2$)

Magnification Used, *M*	Jeffries' Multiplier, *f*, to Obtain Grains/mm²
1	0.0002
10	0.02
25	0.125
50	0.5
75[A]	1.125
100	2.0
150	4.5
200	8.0
250	12.5
300	18.0
500	50.0
750	112.5
1000	200.0

[A] At 75 diameters magnification, Jeffries' multiplier, *f*, becomes unity if the area used is 5625 mm² (a circle of 84.5-mm diameter).

mean grain diameter, *d*, as listed on Plate III (see 10.2.3), is the square root of $\bar{A}$. This grain diameter has no physical significance because it represents the side of a square grain of area $\bar{A}$, and grain cross sections are not square.

11.2 To obtain an accurate count of the number of grains completely within the test circle and the number of grains intersecting the circle, it is necessary to mark off the grains on the template, for example, with a grease pencil or felt tip pen. The precision of the planimetric method is a function of the number of grains counted (see Section 19). The number of grains within the test circle, however, should not exceed about 100 as counting becomes tedious and inaccurate. Experience suggests that a magnification that produces about 50 grains within the test circle is about optimum as to counting accuracy per field. Because of the need to mark off the grains to obtain an accurate count, the planimetric method is ~~less efficient~~ more time consuming than the intercept method (see Section 12).

11.3 Fields should be chosen at random, without bias, as described in 5.2. Do not attempt to choose fields that appear to be typical. Choose the fields blindly and select them from different locations on the plane of polish.

11.4 By original definition, a microscopically-determined grain size of No. 1 has 1.000 grains/in.² at 100X, hence 15.500 grains/mm² at 1X. For areas other than the standard circle, determine the actual number of grains per square millimetre, N_A, and find the nearest size from Table 4. The ASTM grain size number, *G*, can be calculated from N_A (number of grains per mm² at 1X) using (Eq 1) in Table 6.

11.5 This approach assumes that, on average, half of the grains intersecting the test circle are within the circle while half are outside the circle. This assumption is valid for a straight line through a grain structure, but not necessarily for a curved line. ~~The bias created by this assumption increases~~ It has been stated that as the number of grains inside the test circle ~~decreases. If the number of grains within the test circle is at least 50, the bias~~decreased, bias was introduced. However, experiments have shown no bias, but excessive data scatter as (n_{inside} ~~is~~+ $0.5n_{intercepted}$ ~~about 2%.~~) decreased below 50.

11.5.1 ~~There is a~~ A simple way ~~(to~~4) ~~to avoid this bias, irrespective of the number of grains inside the test figure - use a square or rectangulat test area.~~ reduce the data scatter for coarse grained structures where high counts cannot be made, is to use a rectangle rather than a circle, as recommended by Saltykov(**4**). However, the counting procedure must be modified slightly. First, it is assumed that the grains intersecting each of the four corners are, on average, one fourth within the figures and three-fourths outside. These four corner grains together equal one grain within the test box.

11.5.2 Ignoring the four corner grains, a count is made of N_{Inside}, the grains completely within the box, and of $N_{Intercepted}$, the grains intersected by the four sides of the box. Eq 4 now becomes:

$$N_A = (M^2/A)(N_{\text{Inside}} + 0.5\,N_{\text{Intercepted}} + 1) \tag{5}$$

where *M* is the magnification, *A* is the test figure area in mm² and N_A is the number of grains per square millimeter at 1×. Select the fields at random, as described in 11.3. It is recommended that enough fields should be evaluated so that a total of ~700 grains are counted which will usually provide a 10% relative accuracy (see Appendix X1, ~~paragraph~~section X1.3.2). Experiments have demonstrated that a consistent average grain size, *G*, can be obtained using the Saltykov (**4**) rectangle method down to lower counts of ($n_{inside} + 0.5n_{intercepted} + 1$) than with the Jeffries' (**3**) circular test grid.

11.5.3 The average grain area, $\bar{A}$, is the reciprocal of N_A and the mean grain diameter, d, is the square root of $\bar{A}$, as described in 11.1. The ASTM grain size number, *G*, can be estimated using the data in Table 4, or can be calculated from N_A using Eq (1) in Table 6.