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Standard Test Methods for Determining Average Grain Size[1]

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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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.8 The paragraphs appear in the following order:

[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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1.9 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

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:

$$N_{AE} = 2^{G-1} \quad (1)$$

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.

3.2.3 *grain boundary*—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, P*—determination of the number of times a test line cuts across, or is tangent 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, 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.

[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.

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 mm² at 1X.
$N_{A\alpha}$ = number of α grains per mm² at 1X in a two phase (constituent) microstructure.
N_{AE} = number of grains per inch² 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 (see Section 16).

4.3 In case of dispute, the 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.