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Standard Test Methods for Determining Average Grain Size¹

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This standard has been approved for use by agencies of the Department of Defense to replace Methods 31 1.1 and 312 of Federal Test Method Standard No. 151b. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the 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 quite 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 methods may also be applied to nonmetallic materials with structures having appearances similar to those of the metallic structures shown in the comparison charts.

1.2 The paragraphs appear in the following order:

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1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems 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 Specimens²
- E 29 Recommended Practice for Indicating Which Places of Figures Are to Be Considered Significant in Specified Limiting Values³
- E 45 Practice for Determining the Inclusion Content of Steel²
- E 562 Practice for Determining Volume Fraction by Systematic Manual Point Count²
- E 883 Guide for Metallographic Photomicrography²
- E 1181 Test Methods for Characterizing Duplex Grain Sizes²

2.2 Adjuncts

- 2.2.1 For a complete adjunct list, see Appendix X1.

3. Significance and Use

3.1 These 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 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:

3.1.1 *Comparison Procedure*—The comparison procedure is a visual estimation for which the results are generally

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² Annual Book of ASTM Standards, Vol 03.01.

³ Annual Book of ASTM Standards, Vol 14.02.



Documents

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TABLE 1 Suggested Comparison Charts for Metallic Materials

NOTE—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	100×
Copper and copper-base alloys (see Annex A4)	III	75×
Iron and steel:		
Austenitic	II or IV	100×
Ferritic	I	100×
Carburized	IV	100×
Stainless	II	100×
Magnesium and magnesium-base alloys	I or II	100×
Nickel and nickel-base alloys	II	100×
Super-strength alloys	I or II	100×
Zinc and zinc-base alloys	I or II	100×

within plus or minus a whole grain size number of the value determined with the intercept method.

3.1.2 Planimetric Procedure—The planimetric procedure is to be treated as an estimation method generally valid only to plus or minus a half grain size number when no statistical control has been applied. When sufficient measurements have been made and statistically analyzed to comply with the requirements of Section 13, the result may be stated to have been determined to plus or minus a quarter grain size number.

3.1.3 Intercept Procedure—The intercept procedure is to be treated as an estimation method generally valid only to plus or minus a half grain size number when no statistical control has been applied. When sufficient measurements

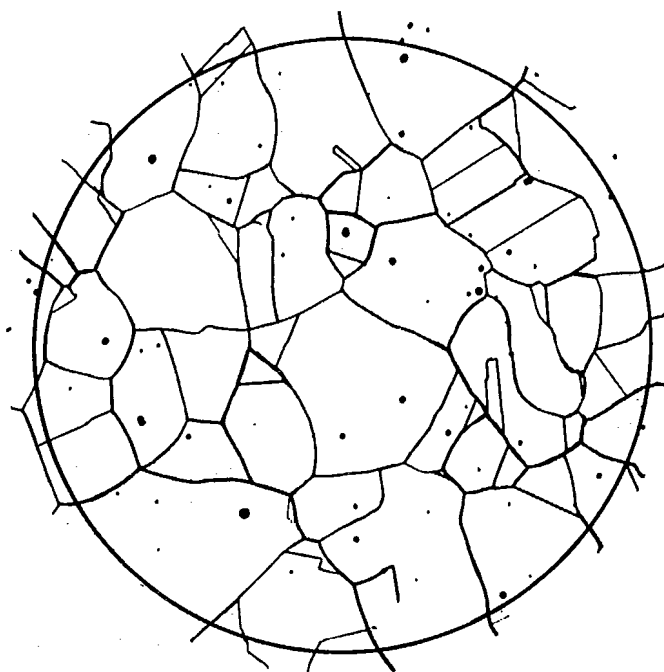


FIG. 2 Example of Twin Grains (Flat Etch) from Plate II. Grain Size No. 3 at 100×

have been made and statistically analyzed to comply with the requirements of Section 13, the result may be stated to have been determined to the precision indicated, but not normally closer than plus or minus a tenth of a grain size number.

3.2 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.

3.3 In case of dispute, the intercept procedure shall be the referee procedure in all cases.

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

3.5 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.

4. Description of Grain Area

4.1 Grain—For the purposes of applying these methods, a grain shall be considered as all that area within the confines of the original (primary) boundary. In materials having twinned grain structures, a crystal and its twin bands shall be considered as one grain.

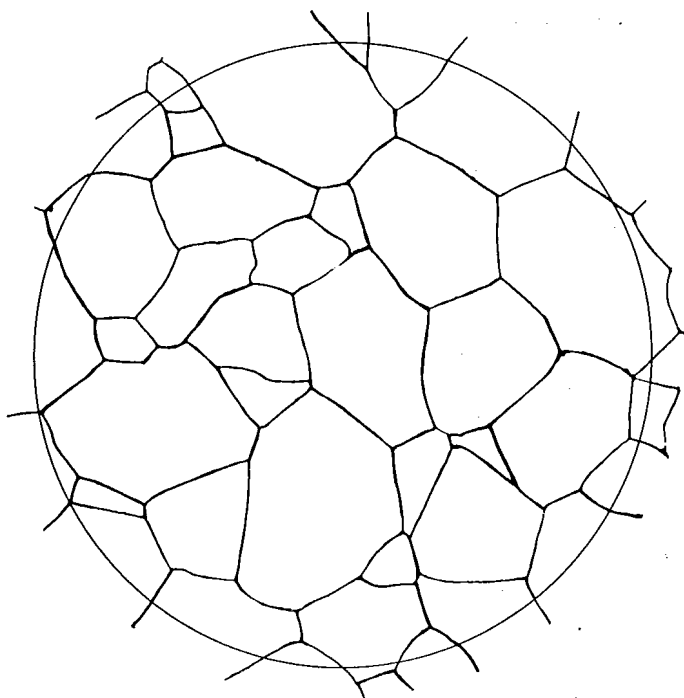


FIG. 1 Example of Untwinned Grains (Flat Etch) from Plate I. Grain Size No. 3 at 100×



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

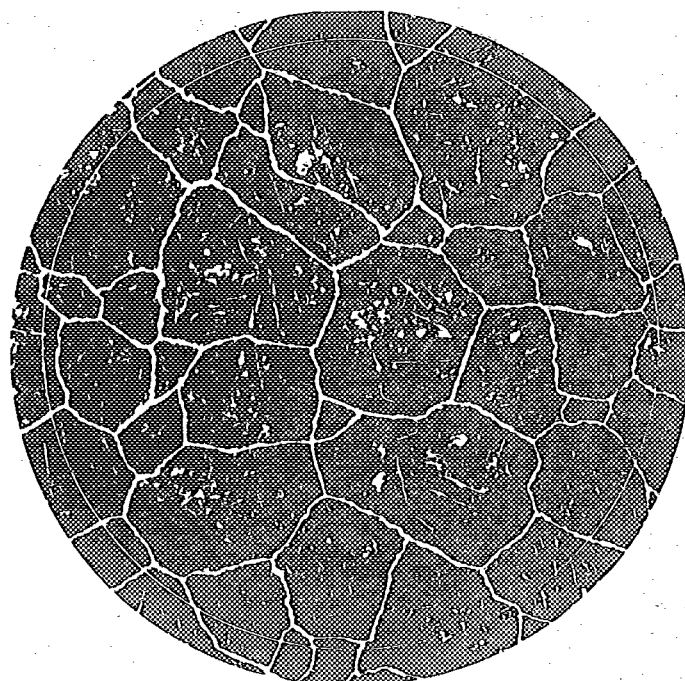


FIG. 4 Example of Austenite Grains in Steel from Plate IV. Grain Size No. 3 at 100×

4.2 Grain Size—In materials consisting of two or more constituents, the grain size shall refer to that of the matrix, except that, in those materials wherein the second phase is of sufficient amount, size, or continuity to be significant, the grain size may be estimated and reported separately. Minor constituent phases, inclusions, and additives are not normally considered in the estimation of grain size.

4.3 Subgrains—The sizes of subgrains may be estimated by the same methods applicable to the grains themselves.

5. Generalities of Application

5.1 It is important, in using these methods, to recognize that the estimation of average grain size is not a precise 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. Preparation of Specimen

6.1 The specimen shall be prepared and etched according to the metallographic procedures recommended in Methods E 3.

7. Preparation of Photomicrographs

7.1 When photomicrographs are used for estimating the average grain size, they shall be prepared in accordance with Guide E 883.

8. Comparison Procedure

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

8.2 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:⁴

⁴ Plates I, II, III, and IV are available from ASTM Headquarters. Order PCN 12-501120-10 (Plate I), 12-501120-20 (Plate II), 12-501120-30 (Plate III), and 12-501120-40 (Plate IV). A combination of all four plates is also available. Order PCN 12-501121-28.

TABLE 2 Micro-Grain Size Relationships Computed for Uniform Randomly Oriented Equiaxed Grains

NOTE—For diameters in inches, see Table 4 (divide by 100).

ASTM Micro-Grain Size Number G	"Diameter" of Average Grain Section ^A		Average Intercept Distance ^B $\bar{L}$, mm	Intercept Count, n/l per mm	Area of Average Grain Section, $\bar{a}$, mm ²	Calculated Number of Grains per mm ³ , n/v ^C	Average	
	Nominal d_n , mm	Feret's d_f , mm					Grains per mm ² at 1 $\times$, ^D n/a	Grains per in. ² at 100 $\times$, n/a
00 ^E	0.51	0.570	0.453	2.210	0.258	6.11	3.88	0.250
0	0.36	0.403	0.320	3.125	0.129	17.3	7.75	0.500
0.5	0.30	0.339	0.269	3.716	0.0912	29.0	11.0	0.707
1.0	0.25	0.285	0.226	4.42	0.0645	48.8	15.50	1.000
1.5	0.21	0.240	0.190	5.26	0.0456	82	21.9	1.414
(1.7) ^F	0.200	0.226	0.177	5.64	0.0400	100	25.0	1.613
2.0	0.18	0.202	0.160	6.25	0.0323	138	31.0	2.000
2.5	0.15	0.170	0.135	7.43	0.0228	232	43.8	2.828
	μm	μm	μm		$\text{mm}^2 \times 10^{-3}$			
3.0	125	143	113	8.84	16.1	391	62.0	4.000
(3.2) ^F	120	135	106	9.41	14.4	463	69.4	4.480
3.5	105	120	95	10.51	11.4	657	87.7	5.657
(3.7) ^F	100	113	89	11.29	10.0	800	100	6.452
4.0	90	101	80.0	12.5	8.07	1105	124	8.000
4.5	75	85	67.3	14.9	5.70	1859	175	11.31
(4.7) ^F	70	79	62.0	16.1	4.90	2331	204	13.17
5.0	65	71	56.6	17.7	4.03	3126	248	16.00
(5.2) ^F	60	68	53.2	18.8	3.60	3708	278	17.92
5.5	55	60	47.6	21.0	2.85	5258	351	22.63
(5.7) ^F	50	56	44.3	22.6	2.50	6400	400	25.81
6.0	45	50	40.0	25.0	2.02	8842	496	32.00
(6.4) ^F	40	45	35.4	28.2	1.60	12 500	625	40.32
6.5	38	42	33.6	29.7	1.43	14 871	701	45.25
(6.7) ^F	35	39	31.0	32.2	1.23	18 659	816	52.67
7.0	32	36	28.3	35.4	1.008	25 010	992	64.00
(7.2) ^F	30	34	26.6	37.6	0.900	29 630	1111	71.68
7.5	27	30	23.8	42.0	0.713	41 061	1403	90.51
(7.7) ^F	25	28	22.2	45.1	0.625	51 200	1600	103.23
	μm	μm	μm		$\text{mm}^2 \times 10^{-6}$	$\times 10^6$	$\times 10^3$	
8.0	22	25	20.0	50.0	504	0.0707	1.98	128.0
(8.4) ^F	20	23	17.7	56.4	400	0.1000	2.50	161.3
8.5	19	21	16.8	59.5	356	0.1190	2.81	181.0
9.0	16	18	14.1	70.7	252	0.200	3.97	256.0
(9.2) ^F	15	17	13.3	75.2	225	0.237	4.44	286.7
9.5	13	15	11.9	84.1	178	0.336	5.61	362.0
10.0	11	13	10.0	100	126	0.566	7.94	512.0
(10.3) ^F	10	11.3	8.86	113	100	0.800	10.00	645.2
10.5	9.4	10.6	8.41	119	89.1	0.952	11.22	724.1
(10.7) ^F	9.0	10.2	7.98	125	81.0	1.097	12.35	796.5
11.0	8	8.9	7.07	141	63.0	1.600	15.87	1024
(11.4) ^F	7.0	7.9	6.20	161	49.0	2.332	20.41	1317
11.5	6.7	7.5	5.95	168	44.6	2.692	22.45	1448
(11.8) ^F	6.0	6.8	5.32	188	36.0	3.704	27.78	1792
12.0	5.6	6.3	5.00	200	31.5	4.527	31.7	2048
(12.3) ^F	5.0	5.6	4.43	226	25.0	6.40	40.0	2581
12.5	4.7	5.3	4.20	238	22.3	7.61	44.9	2896
13.0	4.0	4.5	3.54	283	15.8	12.80	63.5	4096
13.5	3.3	3.7	2.97	336	11.1	21.54	89.8	5793
(13.8) ^F	3.0	3.4	2.66	376	9.0	29.6	111.1	7168
14.0	2.8	3.2	2.50	400	7.88	36.2	127	8192
(14.3) ^F	2.5	2.8	2.22	451	6.25	51.2	160	10323

^A Feret's diameter = height between tangents; $d_f = \bar{a}/\bar{L}$. Values of d_n and d_f rounded to digits shown.

^B Value of Heyn Intercept or mean free path.

^C Computation of n/v based on grains averaging to spherical shape for which $n/v = 0.5659 (n/l)^3$.

^D To obtain grains per mm² at 100 $\times$, multiply by 10^{-4} .

^E The use of "00" is recommended instead of "minus 1" to avoid confusion.

^F The G values shown in parentheses are calculated to one decimal place and correspond to some of the nominal "diameter" sizes, (d_n) customarily used in reporting average grain size by the copper and brass industry.

8.2.1 Plate I—Untwinned grains (flat etch). Includes grain size numbers 00, 0, 1/2, 1, 1 1/2, 2, 2 1/2, 3, 3 1/2, 4, 4 1/2, 5, 5 1/2, 6, 6 1/2, 7, 7 1/2, 8, 8 1/2, 9, 9 1/2, 10, at 100 $\times$.

8.2.2 Plate II—Twinned grains (flat etch). Includes grain size numbers, 1, 2, 3, 4, 5, 6, 7, 8, at 100 $\times$.

8.2.3 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 75 $\times$.

8.2.4 Plate IV—Austenite grains in steel (McQuaid-Ehn). Includes grain size numbers 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, at 100 $\times$.

TABLE 3 Relationships Between the Actual Grain Size of Specimens Viewed at Various Magnifications and the Standard Series of Photomicrographs

Specimen Magnification		Actual Grain Size of Specimen, Expressed as "Diameter" of Average Cross Section When Specimen Image, at Magnification Indicated, ^A Matches Standard Series of Photographs										
		Standard Series of Photomicrographs at 100×										
ASTM Micro-Grain Size Number		0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
100×	mm	0.360	0.300	0.250	0.210	0.180	0.150	0.130	0.110	0.090	0.075	0.065
	in.	0.014	0.012	0.010	0.008	0.007	0.006	0.005	0.004	0.0035	0.003	0.0025
75×	mm	0.480	0.400	0.330	0.280	0.240	0.210	0.170	0.140	0.120	0.100	0.085
	in.	0.019	0.016	0.013	0.011	0.009	0.008	0.0065	0.0055	0.0045	0.004	0.0033
50×	mm	0.720	0.600	0.500	0.420	0.360	0.300	0.250	0.210	0.180	0.150	0.130
	in.	0.028	0.024	0.020	0.016	0.014	0.012	0.010	0.008	0.007	0.006	0.005
25×	mm	1.440	1.200	1.000	0.840	0.720	0.600	0.500	0.420	0.360	0.300	0.250
	in.	0.056	0.047	0.040	0.033	0.028	0.024	0.020	0.016	0.014	0.012	0.010
ASTM Micro-Grain Size Number		5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	
100×	mm	0.055	0.045	0.035	0.030	0.026	0.022	0.019	0.016	0.013	0.011	
	in.	0.002	0.0018	0.0014	0.0012	0.001	0.0009	0.0007	0.0006	0.0005	0.0004	
75×	mm	0.075	0.060	0.045	0.040	0.035	0.030	0.025	0.020	0.018	0.015	
	in.	0.003	0.0023	0.0018	0.0016	0.0014	0.0012	0.001	0.0008	0.0007	0.0006	
50×	mm	0.110	0.090	0.075	0.065	0.055	0.045	0.035	0.030	0.026	0.022	
	in.	0.004	0.0035	0.003	0.0025	0.002	0.0018	0.0014	0.0012	0.001	0.0009	
25×	mm	0.210	0.180	0.150	0.130	0.110	0.090	0.075	0.065	0.055	0.045	
	in.	0.008	0.007	0.006	0.005	0.004	0.0035	0.003	0.0025	0.002	0.0018	
Standard Series of Photomicrographs at 75× (Plate III) ^B												
25×	mm	0.030	0.045	0.060	0.080	0.110	0.140	0.180	0.210	0.270	0.360	0.450
50×	mm	0.015	0.020	0.030	0.040	0.050	0.070	0.080	0.090	0.100	0.140	0.220
75×	mm	0.010	0.015	0.020	0.025	0.035	0.045	0.050	0.060	0.070	0.090	0.150
100×	mm	...	0.010	0.015	0.020	0.025	0.035	0.040	0.045	0.050	0.070	0.150

^A It is recommended that the macro-grain size numbers (see 8.12) be used for grain sizes larger than 0.5 mm (0.02 in.). 25× be used only for grain sizes larger than 0.210 mm (0.008 in.), that 50× be used only for grain sizes larger than 0.075 mm (0.003 in.). For the smaller grain sizes, greater accuracy generally can be secured by increasing the magnification. This table can be used for comparisons at 250×, 300×, 500×, 750×, or 1000× by dividing by 10 the grain size indicated at 25×, 30×, 50×, 75×, or 100×, respectively. Thus, at 250×, a grain size which will match the same standard photograph of 0.050 mm (0.0015 in.) at 75×, will be an 0.015 mm grain size (0.150 at 25× divided by 10).

^B The values shown in this table have been rounded to approximate commercial usage. See Table 2 for exact values.

8.3 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 Figs. 1, 2, 3, and 4.

8.4 The estimation of micro-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 to the nearest appropriate unit listed in Table 2.

8.5 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.

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

8.7 When the grains are of a size outside the range covered by the standard photographs, or when magnifications of 75× or 100× are not satisfactory, other magnifications may be employed for comparison by using the relationships given in Note 2 and Table 3. 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:

$$Q = 2 \log_2 (M/M_b) \\ = 6.64 \log_{10} (M/M_b)$$

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 (75× or 100×), to yield the true ASTM grain-size number. Thus, for a magnification of 25×, the true ASTM grain-size number is 4 numbers lower than that of the corresponding photomicrograph at 100× ($Q = -4$). Likewise, for 400×, the true ASTM grain-size number is 4 numbers higher ($Q = +4$) than that of the corresponding photomicrograph at 100×. Similarly, for 300×, the true ASTM grain-size number is 4 numbers higher than that of the corresponding photomicrograph at 75×.

8.8 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 difficult. When the sample 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.

TABLE 4 Macro-Grain Size Relations Computed for Uniform Randomly Oriented Equiaxed Grains

NOTE—Use of micro-grain size numbers (Table 2) is recommended for all grain sizes higher than M-14. Micro-size numbers may be converted to macro-size numbers by adding 13.288 size numbers.

ASTM Macro-Grain Size Number (M)G	ASTM Micro-Grain Size Number G	"Diameter" of Average Grain Section			Average Intercept Distance ^A		Intercept Count <i>N</i> in 100 mm	Area of Average Grain Section		Grains per Area at 1 ×	
		Nominal <i>d_n</i>		Feret's <i>d_F</i> , mm	<i>L_v</i> , mm	<i>L_v</i> , in.		<i>a_v</i> , mm ²	<i>a_v</i> , in. ²	<i>n_a</i> , mm ² × 10 ⁻³	<i>n_a</i> , in. ²
		mm	in.								
M-0	...	36	1.4	40.3	32.00	1.26	3.125	1290	2.00	0.775	0.50
M-0.5	...	30	1.2	33.9	26.91	1.06	3.716	912	1.41	1.10	0.71
M-1	...	25	1.0	28.5	22.63	0.891	4.419	645	1.00	1.55	1.00
M-1.5	...	21	0.84	24.0	19.03	0.749	5.256	456	0.707	2.19	1.41
M-2	...	18	0.71	20.1	16.00	0.630	6.25	323	0.500	3.10	2.00
M-2.5	...	15	0.59	17.0	13.45	0.530	7.43	228	0.354	4.39	2.83
M-3	...	13	0.50	14.3	11.31	0.445	8.84	161	0.250	6.20	4.00
M-3.5	...	11	0.42	12.0	9.51	0.375	10.51	114	0.177	8.77	5.66
M-4	...	9	0.35	10.1	8.000	0.315	12.5	80.6	0.125	12.40	8.00
M-4.5	...	7.5	0.30	8.5	6.727	0.265	14.9	57.0	0.088	17.53	11.31
M-5	...	6.5	0.25	7.1	5.657	0.223	17.7	40.3	0.063	24.80	16.00
M-5.5	...	5.5	0.21	6.0	4.757	0.187	21.0	28.5	0.044	35.08	22.63
M-6	...	4.5	0.18	5.0	4.000	0.157	25.0	20.2	0.031	49.60	32.00
M-6.5	...	4	0.15	4.2	3.364	0.132	29.7	14.3	0.022	70.14	45.25
M-7	...	3.2	0.125	3.6	2.828	0.111	35.4	10.1	0.0156	99.20	64.00
M-7.5	...	2.7	0.105	3.0	2.378	0.094	42.0	7.2	0.0110	140.3	90.51
			in. × 10 ⁻³			in. × 10 ⁻³			in. ² × 10 ⁻³		
M-8	...	2.2	88	2.5	2.000	78.7	50.0	5.04	7.81	198.4	128.0
M-8.5	...	1.9	74	2.1	1.682	66.2	59.5	3.56	5.52	280.6	181.0
M-9	...	1.6	63	1.8	1.414	55.7	70.7	2.52	3.91	396.8	256.0
M-9.5	...	1.3	53	1.5	1.189	46.8	84.1	1.78	2.76	561.1	362.0
M-10	...	1.1	44	1.26	1.000	39.4	100.0	1.26	1.95	793.6	512
M-10.5	...	0.95	37	1.06	0.841	33.1	112.2	0.891	1.38	1122	724
M-11	...	0.80	31	0.89	0.707	27.8	141.4	0.630	0.976	1587	1024
M-11.5	...	0.67	26	0.75	0.595	23.4	168.2	0.446	0.690	2244	1448
M-12	...	0.56	22	0.63	0.500	19.7	200.0	0.315	0.488	3174	2048
(M-12.3)	00	0.51	20	0.57	0.453	17.8	221.0	0.258	0.400	3875	2500
M-12.5	...	0.47	18.6	0.53	0.420	16.6	237.8	0.223	0.345	4489	2896
M-13	...	0.40	15.6	0.45	0.354	13.9	282.8	0.158	0.244	6349	4096
(M-13.3)	0	0.36	14.1	0.40	0.320	12.6	312.5	0.129	0.200	7750	5000
M-13.5	...	0.33	13.1	0.37	0.297	11.7	336.4	0.111	0.172	8979	5793
(M-13.8)	0.5	0.30	11.9	0.34	0.269	10.6	317.6	0.0912	0.141	10 960	7071
M-14	...	0.28	11.0	0.32	0.250	9.84	400.0	0.0788	0.122	12 698	8192
(M-14.3)	1.0	0.25	10.0	0.28	0.226	8.91	442	0.0645	0.100	15 500	10 000

^A Value of Heyn intercept or mean free path.

8.9 The use of transparencies⁵ 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.

8.10 No particular significance should be attached to the fact that different observers often obtain slightly different results, provided the different results fall within the confi-

dence limits reasonably expected with the procedure used.

8.11 There is a possibility when an operator makes repeated checks on the same sample using the comparison method that he will be prejudiced by his first estimate. This disadvantage can be overcome, when necessary, by changes in magnification, through bellows extension, or objective or eyepiece replacement between estimates (1)⁶.

8.12 Make the estimation of macro-grain sizes (extremely coarse) by direct comparison, at a magnification of 1×, 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

⁵ Transparencies of the various grain sizes in Plate I are available from ASTM Headquarters. Order PCN 12-501122-28 for set. Transparencies of individual grain size groupings are available on request. Order PCN 12-501121-11 (Grain Size 00), 12-501121-12 (Grain Size 0), 12-501121-13 (Grain Size 0.5), 12-501121-14 (Grain Size 1.0), 12-501121-15 (Grain Size 1.5), 12-501121-16 (Grain Size 2.0), 12-501121-17 (Grain Size 2.5), 12-501121-18 (Grain Sizes 3.0, 3.5, and 4.0), 12-501121-19 (Grain Sizes 4.5, 5.0, and 5.5), 12-501121-21 (Grain Sizes 6.0, 6.5, and 7.0), 12-501121-22 (Grain Sizes 7.5, 8.0, and 8.5), and 12-501121-23 (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.

⁶ The boldface numbers in parentheses refer to the list of references appended to these methods.

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

Magnification Used, M	Jeffries' Multiplier, f , to Obtain Grains/mm ²
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).

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 4. For the smaller macro-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:

$$Q_M = 2 \log_2 M \\ = 6.64 \log_{10} M$$

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 1 $\times$, to yield the true ASTM macro-grain size number. Thus, for a magnification of 2 $\times$, the true ASTM macro-grain size number is 2 numbers higher ($Q = +2$), and for 4 $\times$, the true ASTM macro-grain size number is 4 numbers higher ($Q = +4$) than that of the corresponding photograph.

8.13 The comparison procedure shall be applicable for estimating the austenite grain size in ferritic steel after a McQuaid-Ehn test (see Annex A3, A3.2), or after the 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 100 $\times$, 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 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.

8.14 The so-called "Fracture Method" of judging grain size from the appearance of the fracture of hardened steel (2), involves comparison of the specimen under investigation with a set of fracture standards. It has been found that the arbitrarily numbered fracture grain sizes agree well with the correspondingly numbered ASTM grain sizes presented in Table 2. This coincidence makes the fracture grain sizes interchangeable with the austenite grain sizes determined microscopically (except that "duplexed" or mixed grain size is not readily discernible in fractures). The sizes observed microscopically shall be considered the primary standard,

TABLE 6 Anticipated Standard Deviation in Lineal Analysis of an Ideal Specimen

N Intersections Counted	C.V. of N	Standard Deviation of ^A			Bias in Circle, % of $\bar{T}$
		N	$\bar{T}$, %	ASTM No.	
4	0.50	2	+100 -33	-2.0 +1.16	+10
6	0.41	2.45	± 67 +69 -29	± 1.58 -1.51 +0.98	+4.7
10	0.32	3.16	± 49 +46 -24	± 1.25 -1.10 +0.79	+1.7
15	0.26	3.87	± 35 -21 +28	-0.86 +0.66 ± 0.76	+0.7
20	0.22	4.47	+29 -18 ± 24	-0.73 +0.58 ± 0.66	+0.4
30	0.18	5.48	+22 -15 ± 19	-0.58 +0.48 ± 0.53	+0.2
35	0.17	5.92	+20 -14 ± 17	-0.53 +0.45 ± 0.49	+0.13
40	0.16	6.32	+19 -14 ± 16	-0.50 +0.42 ± 0.46	+0.1
50	0.14	7.1	+17 -12 ± 14	-0.44 +0.38 ± 0.41	+0.07
75	0.12	8.7	± 12 ± 10	± 0.33 ± 0.29	+0.03
100	0.10	10.0	± 8 ± 7	± 0.24 ± 0.20	...
150	0.08	12.2	± 6 ± 4.5	± 0.17 ± 0.13	...
200	0.07	14.1	± 3.2	± 0.09	...
300	0.06	17.3			
500	0.045	22.4			
1000	0.03	31.6			

^A Computed from σ of $N = \text{Poisson standard error of counting} = \sqrt{N}$

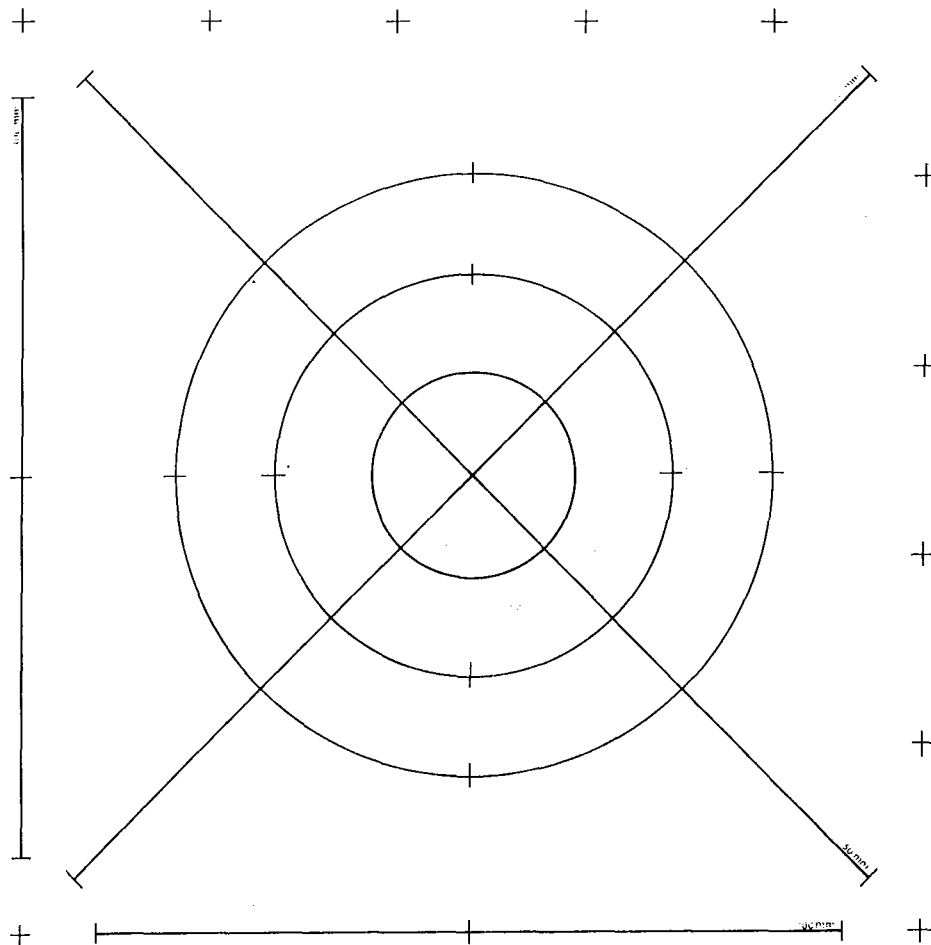
since they can be determined with measuring instruments.

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

9.1 In the planimetric procedure inscribe a circle (see Fig. 11)⁷ or rectangle of known area (usually 5000 mm² to simplify the calculations) on a micrograph or on the ground-glass screen of the metallograph. Select 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 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. Count a minimum of three fields to assure a reasonable average.

9.2 Statistical considerations of the grain-counting methods would require the counting of far more grains per given area than would seem to be practically feasible. Thus, while 100 or more grains per given area may be statistically acceptable for ordinary use, the more practical aspects of grain counting reduce such considerations to a minimum of

⁷ A transparency of Fig. 11 is available from ASTM Headquarters. Order PCN 12-501123-91.



If reproduced to make straight lines marked length:
Straight lines total: 500 mm

Circles are:	Circumference, mm,	Diameter, mm
	250.0	79.58
	166.7	53.05
	83.3	26.53
Total	500.0	

FIG. 5 Test Pattern for Intercept Counting

50 grains per given area; areas containing less than 50 grains being not acceptable. However, for higher orders of accuracy such as in experimental work, areas containing 500 to 1000 or more grains may be used.

9.3 Take care in choosing the location of the fields used for making the count. They must be "representative" in the sense described in 5.2.

9.4 By original definition, Micro Grain Size No. 1 has 1,000 grains/in.² at 100×, hence 15,500 grains/mm² at 1× or /10 000 mm² at 100×. For areas other than the standard circle, determine the actual number of grains per square millimetre and find the nearest size from Table 2. For magnifications other than 100×, add the *Q* values from Note 2 (Section 8).

9.5 When the grains are not equiaxed, make a grain count on three mutually perpendicular planes that are determined by the longitudinal, transverse, and normal directions. Designate the number of grains per square millimetre

for these planes as n_{ll} , n_{lm} , and n_{tm} , respectively. The number of grains per cubic millimetre, n_{lm} , is then given by $0.8 \sqrt{n_{ll} \times n_{lm} \times n_{tm}}$. Subscripts, which are appended to the ASTM grain size number to show grain shape, are n_{tm}/n_{ll} and n_{lm}/n_{ll} .

10. General Intercept Procedures

10.1 Intercept procedures are more convenient to use than the planimetric procedure. These procedures are amenable to use with various types of machine aids. It is strongly recommended that at least a manual tally counter be used with all intercept procedures in order to prevent normal errors in counting and to eliminate bias which may occur when counts appear to be running higher or lower than anticipated.

10.2 Intercept procedures are recommended particularly for all structures that depart from the uniform equiaxed form. For anisotropic structures, procedures are available