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SURFACE VEHICLE RECOMMENDED PRACTICE

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Grain Size Determination of Steels

Foreword—This Document has not changed other than to put it into the new SAE Technical Standards Board Format. References were added as Section 2. All other section numbers have changed accordingly.

[This SAE Recommended Practice is based on ASTM E 112, Standard Methods for Estimating the Average Grain Size of Metals. It is published here with permission of the ASTM for convenience of SAE Handbook users.]

1. ***Scope***—This classification for grain size comprises three sets of comparison charts to be used for determining grain size. These charts are presented in three categories as follows:[1]

   Plate I - Untwinned grains (flat etch)

   Plate II - Twinned grains (flat etch)

   Plate IV - Austenite grains in steel (McQuaid-Ehn test or other test)

   Table 1 lists a number of materials and the comparison charts that are suggested for use in estimating their grain size by the comparison method.

   NOTE—The suggestions in Table 1 are based upon the customary practices in industry. For specimens prepared according to special techniques, the appropriate comparison chart should be selected on a structural appearance basis as described in the Scope.

TABLE 1—SUGGESTED COMPARISON CHARTS

Material	Plate No.	Basic Magnification
Austenitic	II or IV	100x
Ferritic	I	100x
Carburized	IV	100x
Stainless	II	100x
Super-Strength Alloys	I or II	100x

1. Plates I, II, and IV of ASTM E 112 may be obtained from ASTM Headquarters, 100 Barr Harbor Street, West Conshocken, PA 19428-2959 at a nominal cost. Examples of grain size standards from Plates I, II and IV are shown in Figures 1, 2, and 3.

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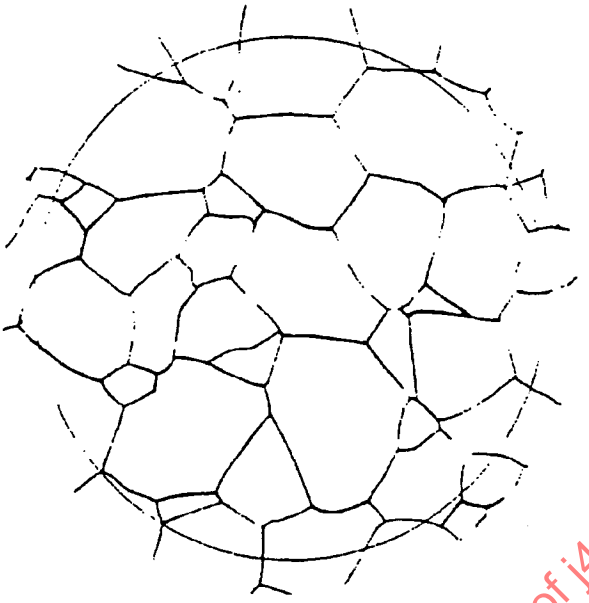

FIGURE 1—EXAMPLE OF UNTWINNED GRAINS (FLAT ETCH) FROM PLATE I.
GRAIN SIZE NO. 3 AT 100X

2. *References*

2.1 Applicable Publication—The following publication forms a part of the specification to the extent specified herein. Unless otherwise indicated, the latest revision of SAE publications shall apply.

2.1.1 ASTM PUBLICATION—Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959

ASTM E 112—Standard Methods for Estimating the Average Grain Size of Metals

3. *Establishing Ferrite Grain Size*—Ferrite grain size is already established in the sample to be examined by prior processing.

In hot worked material, a specimen representing a plane transverse to the direction of working is generally suitable. However, on flat rolled material, or any other in which elongation is likely to be encountered, both a transverse plane and one parallel to the direction of working should be examined.

3.1 Revealing the Ferrite Grain Size—The specimen may be prepared by appropriate polishing and etching with a 5% nital solution for 10 s (more for alloy steels) which generally produces good grain boundary delineation.

4. *Establishing Austenite Grain Size*—Numerous methods are in use for establishing austenite grain size, and a knowledge of grain coarsening behavior is helpful in deciding which method to use. The size of austenite grains, in any particular steel, depends primarily on the temperature to which that steel is heated and the time it is held at the temperature. It should be remembered that the atmosphere in heating may affect the grain growth behavior at the outside of the piece.

Austenite grain size is influenced by most previous treatments to which steel may have been subjected, as, for example, quenching, normalizing, hot working, and cold working. It is therefore advisable, when testing for austenite grain size, to consider the effects of prior or subsequent treatments on the precise piece (or typical piece) which is under consideration.

As may be agreed upon between the manufacturer and the purchaser, austenite grain size shall in this classification be established by either of the following:

a. Carburizing at 925 °C (1700 °F) for 8 h (the McQuaid-Ehn test), which is recommended for carburizing grades, and often employed for other grades as well.
b. Heating at a temperature not over 28 °C (50 °F) above the normal heat treating temperature and for not over 50% more than the normal heat treating time, the normal values being those mutually agreed upon.

The rate of cooling depends on the method of treatment, as will be evident from the methods described in the following paragraphs.

4.1 Revealing the Austenite Grain Size—For revealing austenite grain size the following methods are generally used:

1. Outlining the grains with cementite, as in carburizing (McQuaid-Ehn test) or as high carbon steels. In the hypereutectoid zone of a McQuaid-Ehn test, or in hypereutectoid steels cooled slowly from the austenitic condition, the austenite grain size is outlined by the cementite which precipitated in the grain boundaries. It is therefore possible to read the grain size by etching the micrographic specimen with a suitable etchant, such as nital or picral, or alkaline sodium picrate.

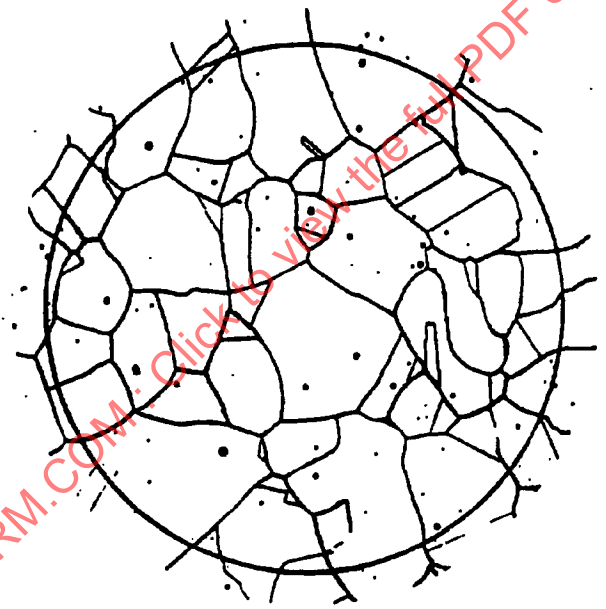

FIGURE 2—EXAMPLE OF TWIN GRAINS (FLAT ETCH) FROM PLATE II.
GRAIN SIZE NO. 3 AT 100X

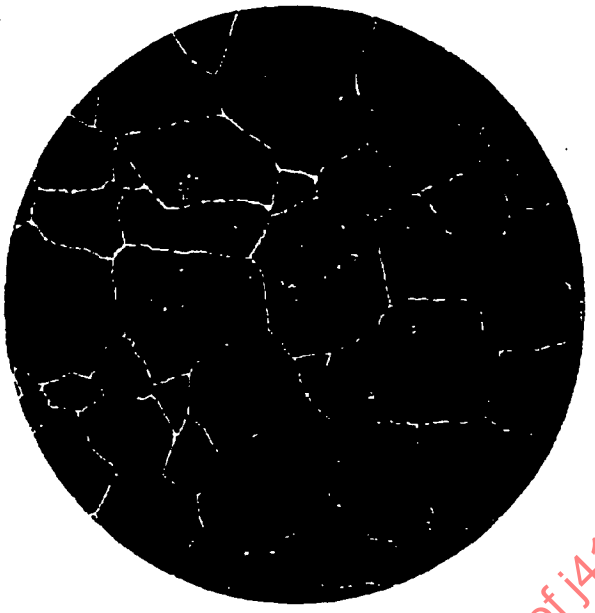

FIGURE 3—EXAMPLE OF AUSTENITE GRAINS IN STEEL FROM PLATE IV.
GRAIN SIZE NO. 3 AT 100X

2. Outlining the grains with ferrite, as in the hypoeutectoid zone in carburizing, or in medium carbon steels generally, or by an interrupted cooling or gradient quench on low carbon steels. Ferrite precipitates in the austenite grain boundaries, thus indicating the austenite grain size in the hypoeutectoid zone in a McQuaid-Ehn test (see Plate Series II). Ferrite similarly outlines the former austenite grains in a medium carbon steel (say 0.50% carbon) when it has been cooled slowly from the austenite range. In low carbon steels (say 0.20% carbon) cooled slowly from the austenite range to room temperature, the amount of ferrite is so large that the former austenite grain size is masked. In this case, the steel may be cooled slowly to an intermediate temperature, to allow only a small amount of ferrite to precipitate, followed by quenching in water; an example would be a piece previously heated to 910 °C (1675 °F), transferred to a furnace at perhaps 730 to 790 °C (1350 to 1450 °F), held at this temperature for perhaps 3 to 5 minutes, and then quenched in water; the austenite grain size would be revealed by small ferrite grains outlining low carbon martensite grains.

3. Fine pearlite outlining of martensite grains, as in eutectoid steels at a not quite fully hardened zone. A method applicable particularly to eutectoid steels, which cannot be judged so readily by some other methods, is either (a) to harden a bar of such size that it is fully hardened at the outside, but not quite fully hardened in the interior, or (b) to employ a "gradient quench" in which the heated piece is for a portion of its length immersed in water and therefore fully hardened, the remainder of the piece projecting above the quenching bath, being therefore not hardened. With either method, there will be a small zone which is almost but not quite fully hardened. In this zone the former austenite grains will consist of martensite grains surrounded by small amounts of fine pearlitic ("nodular troosite"), thus revealing the grain size. These methods are also applicable to steels somewhat higher and lower than the eutectoid composition.

4. Appropriate etching of fully hardened martensite. The former austenite grain size may be revealed in steels fully hardened to martensite by using an etching reagent which develops contrast between the martensite grains. A reagent which has been recommended is 1 g of picric acid, 5 mL of HCl (specific gravity 1.19), and 95 mL of ethyl alcohol. Tempering for 15 min at 230°C (450°F) prior to etching distinctly improves the contrast.

5. Oxidation Method: The oxidation method depends on the fact that when steels are heated in an oxidizing atmosphere, oxidation takes place in part preferentially along the grain boundaries. A common procedure, therefore, is to polish the test specimen to a metallographic polish, heat it in air at the desired temperature for the desired length of time, and then repolish the specimen lightly so as merely to remove scale; whereupon the austenite grain boundaries are visible as outlined by oxide.

5. ***Estimating The Grain Size***—The estimation of micro-grain size should be made by direct comparison at 100 diameters with the appropriate chart and selecting the standard which most nearly matches the image of the test specimen or interpolating between two standards. This estimated grain size should be reported to the nearest appropriate unit listed in Table 2. When the grains are of a size outside the range covered by the comparison charts or when a magnification of 100 is not satisfactory, reference should be made to ASTM E 112.

TABLE 2—MICRO-GRAIN SIZE RELATIONSHIPS

ASTM Micro-Grain Size No.	Calculated Dia of Average Grain		Calculated Area of Average Grain Section		Nominal Grains per sq mm at 1 X	Nominal Grains per sq in at 100 X
	mm	in, X 10^{-3}	sq mm, X 10^{-3}	sq in, X 10^{-6}		
00(1)	0.508	20.0	258	400	3.88	0.250
0.5	0.302	11.9	91.2	141	11.0	0.707
1.0	0.254	10.0	64.5	100	15.5	1.0
1.5	0.214	8.41	45.6	70.7	21.9	1.41
2.0	0.180	7.07	32.3	50.0	31.0	2.0
2.5	0.151	5.95	22.8	35.4	43.8	2.83
3.0	0.127	5.00	16.1	25.0	62.0	4.0
3.5	0.107	4.20	11.4	17.7	87.7	5.66
4.0	0.090	3.54	8.06	12.5	124	8.0
4.5	0.076	2.97	5.70	8.84	175	11.3
5.0	0.064	2.50	4.03	6.25	248	16.0
5.5	0.053	2.10	2.85	4.42	351	22.6
6.0	0.045	1.77	2.02	3.13	496	32.0
6.5	0.038	1.49	1.43	2.21	701	45.3
7.0	0.032	1.25	1.01	1.56	992	64.0
7.5	0.027	1.05	0.713	1.10	1403	90.5
8.0	0.022	0.884	0.504	0.781	1980	128
8.5	0.019	0.749	0.356	0.552	2810	181
9.0	0.016	0.630	0.252	0.391	3970	256
9.5	0.013	0.512	0.178	0.276	5610	362
10.0	0.011	0.433	0.126	0.195	7940	512
10.5	0.0094	0.370	0.089	0.138	11 220	724
11.0	0.0080	0.315	0.063	0.098	15 870	1 024
11.5	0.0067	0.264	0.045	0.070	22 450	1 448
12.0	0.0056	0.221	0.032	0.050	31 700	2 048
12.5	0.0047	0.185	0.022	0.034	44 900	2 896
13.0	0.0040	0.158	0.016	0.025	63 500	1 096
13.5	0.0033	0.130	0.011	0.017	89 800	5 793
14.0	0.0028	0.110	0.008	0.012	127 000	8 192

1. The use of 00 is recommended instead of "–1" or "minus 1" to avoid confusion.