

Steels — Micrographic determination of the apparent grain size

The European Standard EN ISO 643:2003 has the status of a
British Standard

ICS 77.040.99

National foreword

This British Standard is the official English language version of EN ISO 643:2003. It is identical with ISO 643:2003. It supersedes BS 4490:1989 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee ISE/72, Methods of physical and metallographic testing, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this committee can be obtained on request to its secretary.

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the *BSI Catalogue* under the section entitled “International Standards Correspondence Index”, or by using the “Search” facility of the *BSI Electronic Catalogue* or of British Standards Online.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 10 March 2003

Summary of pages

This document comprises a front cover, an inside front cover, the EN ISO title page, the EN ISO foreword page, the ISO title page, pages ii to iv, pages 1 to 35 and a back cover.

The BSI copyright date displayed in this document indicates when the document was last issued.

Amendments issued since publication

Amd. No.	Date	Comments

© BSI 10 March 2003

ISBN 0 580 41396 9

English version

Steels - Micrographic determination of the apparent grain size (ISO 643:2003)

Aciers - Détermination micrographique de la grosseur de
grain apparente (ISO 643:2003)

Stahl - Mikrophotographische Bestimmung der scheinbaren
Korngröße (ISO 643:2003)

This European Standard was approved by CEN on 21 January 2003.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Management Centre has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Slovak Republic, Spain, Sweden, Switzerland and United Kingdom.



EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: rue de Stassart, 36 B-1050 Brussels

Foreword

This document (EN ISO 643:2003) has been prepared by Technical Committee ISO/TC 17 "Steel" in collaboration with Technical Committee ECISS/TC 2 "Steel - Physico-chemical and non-destructive testing", the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by August 2003, and conflicting national standards shall be withdrawn at the latest by August 2003.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Slovak Republic, Spain, Sweden, Switzerland and the United Kingdom.

NOTE FROM CMC The foreword is susceptible to be amended on reception of the German language version. The confirmed or amended foreword, and when appropriate, the normative annex ZA for the references to international publications with their relevant European publications will be circulated with the German version.

Endorsement notice

The text of ISO 643:2003 has been approved by CEN as EN ISO 643:2003 without any modifications.

INTERNATIONAL STANDARD

ISO 643

Second edition
2003-02-15

Steels — Micrographic determination of the apparent grain size

*Aciers — Détermination micrographique de la grosseur de grain
apparente*

ISO 643:2003(E)



Reference number
ISO 643:2003(E)

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
155
156
157
158
159
160
161
162
163
164
165
166
167
168
169
170
171
172
173
174
175
176
177
178
179
180
181
182
183
184
185
186
187
188
189
190
191
192
193
194
195
196
197
198
199
200
201
202
203
204
205
206
207
208
209
210
211
212
213
214
215
216
217
218
219
220
221
222
223
224
225
226
227
228
229
230
231
232
233
234
235
236
237
238
239
240
241
242
243
244
245
246
247
248
249
250
251
252
253
254
255
256
257
258
259
260
261
262
263
264
265
266
267
268
269
270
271
272
273
274
275
276
277
278
279
280
281
282
283
284
285
286
287
288
289
290
291
292
293
294
295
296
297
298
299
300
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
317
318
319
320
321
322
323
324
325
326
327
328
329
330
331
332
333
334
335
336
337
338
339
340
341
342
343
344
345
346
347
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365
366
367
368
369
370
371
372
373
374
375
376
377
378
379
380
381
382
383
384
385
386
387
388
389
390
391
392
393
394
395
396
397
398
399
400
401
402
403
404
405
406
407
408
409
410
411
412
413
414
415
416
417
418
419
420
421
422
423
424
425
426
427
428
429
430
431
432
433
434
435
436
437
438
439
440
441
442
443
444
445
446
447
448
449
450
451
452
453
454
455
456
457
458
459
460
461
462
463
464
465
466
467
468
469
470
471
472
473
474
475
476
477
478
479
480
481
482
483
484
485
486
487
488
489
490
491
492
493
494
495
496
497
498
499
500
501
502
503
504
505
506
507
508
509
510
511
512
513
514
515
516
517
518
519
520
521
522
523
524
525
526
527
528
529
530
531
532
533
534
535
536
537
538
539
540
541
542
543
544
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580
581
582
583
584
585
586
587
588
589
590
591
592
593
594
595
596
597
598
599
600
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
630
631
632
633
634
635
636
637
638
639
640
641
642
643
644
645
646
647
648
649
650
651
652
653
654
655
656
657
658
659
660
661
662
663
664
665
666
667
668
669
670
671
672
673
674
675
676
677
678
679
680
681
682
683
684
685
686
687
688
689
690
691
692
693
694
695
696
697
698
699
700
701
702
703
704
705
706
707
708
709
710
711
712
713
714
715
716
717
718
719
720
721
722
723
724
725
726
727
728
729
730
731
732
733
734
735
736
737
738
739
740
741
742
743
744
745
746
747
748
749
750
751
752
753
754
755
756
757
758
759
760
761
762
763
764
765
766
767
768
769
770
771
772
773
774
775
776
777
778
779
780
781
782
783
784
785
786
787
788
789
790
791
792
793
794
795
796
797
798
799
800
801
802
803
804
805
806
807
808
809
810
811
812
813
814
815
816
817
818
819
820
821
822
823
824
825
826
827
828
829
830
831
832
833
834
835
836
837
838
839
840
841
842
843
844
845
846
847
848
849
850
851
852
853
854
855
856
857
858
859
860
861
862
863
864
865
866
867
868
869
870
871
872
873
874
875
876
877
878
879
880
881
882
883
884
885
886
887
888
889
890
891
892
893
894
895
896
897
898
899
900
901
902
903
904
905
906
907
908
909
910
911
912
913
914
915
916
917
918
919
920
921
922
923
924
925
926
927
928
929
930
931
932
933
934
935
936
937
938
939
940
941
942
943
944
945
946
947
948
949
950
951
952
953
954
955
956
957
958
959
960
961
962
963
964
965
966
967
968
969
970
971
972
973
974
975
976
977
978
979
980
981
982
983
984
985
986
987
988
989
990
991
992
993
994
995
996
997
998
999
1000
1001
1002
1003
1004
1005
1006
1007
1008
1009
1010
1011
1012
1013
1014
1015
1016
1017
1018
1019
1020
1021
1022
1023
1024
1025
1026
1027
1028
1029
1030
1031
1032
1033
1034
1035
1036
1037
1038
1039
1040
1041
1042
1043
1044
1045
1046
1047
1048
1049
1050
1051
1052
1053
1054
1055
1056
1057
1058
1059
1060
1061
1062
1063
1064
1065
1066
1067
1068
1069
1070
1071
1072
1073
1074
1075
1076
1077
1078
1079
1080
1081
1082
1083
1084
1085
1086
1087
1088
1089
1090
1091
1092
1093
1094
1095
1096
1097
1098
1099
1100
1101
1102
1103
1104
1105
1106
1107
1108
1109
1110
1111
1112
1113
1114
1115
1116
1117
1118
1119
1120
1121
1122
1123
1124
1125
1126
1127
1128
1129
1130
1131
1132
1133
1134
1135
1136
1137
1138
1139
1140
1141
1142
1143
1144
1145
1146
1147
1148
1149
1150
1151
1152
1153
1154
1155
1156
1157
1158
1159
1160
1161
1162
1163
1164
1165
1166
1167
1168
1169
1170
1171
1172
1173
1174
1175
1176
1177
1178
1179
1180
1181
1182
1183
1184
1185
1186
1187
1188
1189
1190
1191
1192
1193
1194
1195
1196
1197
1198
1199
1200
1201
1202
1203
1204
1205
1206
1207
1208
1209
1210
1211
1212
1213
1214
1215
1216
1217
1218
1219
1220
1221
1222
1223
1224
1225
1226
1227
1228
1229
1230
1231
1232
1233
1234
1235
1236
1237
1238
1239
1240
1241
1242
1243
1244
1245
1246
1247
1248
1249
1250
1251
1252
1253
1254
1255
1256
1257
1258
1259
1260
1261
1262
1263
1264
1265
1266
1267
1268
1269
1270
1271
1272
1273
1274
1275
1276
1277
1278
1279
1280
1281
1282
1283
1284
1285
1286
1287
1288
1289
1290
1291
1292
1293
1294
1295
1296
1297
1298
1299
1300
1301
1302
1303
1304
1305
1306
1307
1308
1309
1310
1311
1312
1313
1314
1315
1316
1317
1318
1319
1320
1321
1322
1323
1324
1325
1326
1327
1328
1329
1330
1331
1332
1333
1334
1335
1336
1337
1338
1339
1340
1341
1342
1343
1344
1345
1346
1347
1348
1349
1350
1351
1352
1353
1354
1355
1356
1357
1358
1359
1360
1361
1362
1363
1364
1365
1366
1367
1368
1369
1370
1371
1372
1373
1374
1375
1376
1377
1378
1379
1380
1381
1382
1383
1384
1385
1386
1387
1388
1389
1390
1391
1392
1393
1394
1395
1396
1397
1398
1399
1400
1401
1402
1403
1404
1405
1406
1407
1408
1409
1410
1411
1412
1413
1414
1415
1416
1417
1418
1419
1420
1421
1422
1423
1424
1425
1426
1427
1428
1429
1430
1431
1432
1433
1434
1435
1436
1437
1438
1439
1440
1441
1442
1443
1444
1445
1446
1447
1448
1449
1450
1451
1452
1453
1454
1455
1456
1457
1458
1459
1460
1461
1462
1463
1464
1465
1466
1467
1468
1469
1470
1471
1472
1473
1474
1475
1476
1477
1478
1479
1480
1481
1482
1483
1484
1485
1486
1487
1488
1489
1490
1491
1492
1493
1494
1495
1496
1497
1498
1499
1500
1501
1502
1503
1504
1505
1506
1507
1508
1509
1510
1511
1512
1513
1514
1515
1516
1517
1518
1519
1520
1521
1522
1523
1524
1525
1526
1527
1528
1529
1530
1531
1532
1533
1534
1535
1536
1537
1538
1539
1540
1541
1542
1543
1544
1545
1546
1547
1548
1549
1550
1551
1552
1553
1554
1555
1556
1557
1558
1559
1560
1561
1562
1563
1564
1565
1566
1567
1568
1569
1570
1571
1572
1573
1574
1575
1576
1577
1578
1579
1580
1581
1582
1583
1584
1585
1586
1587
1588
1589
1590
1591
1592
1593
1594
1595
1596
1597
1598
1599
1600
1601
1602
1603
1604
1605
1606
1607
1608
1609
1610
1611
1612
1613
1614
1615
1616
1617
1618
1619
1620
1621
1622
1623
1624
1625
1626
1627
1628
1629
1630
1631
1632
1633
1634
1635
1636
1637
1638
1639
1640
1641
1642
1643
1644
1645
1646
1647
1648
1649
1650
1651
1652
1653
1654
1655
1656
1657
1658
1659
1660
1661
1662
1663
1664
1665
1666
1667
1668
1669
1670
1671
1672
1673
1674
1675
1676
1677
1678
1679
1680
1681
1682
1683
1684
1685
1686
1687
1688
1689
1690
1691
1692
1693
1694
1695
1696
1697
1698
1699
1700
1701
1702
1703
1704
1705
1706
1707
1708
1709
1710
1711
1712
1713
1714
1715
1716
1717
1718
1719
1720
1721
1722
1723
1724
1725
1726
1727
1728
1729
1730
1731
1732
1733
1734
1735
1736
1737
1738
1739
1740
1741
1742
1743
1744
1745
1746
1747
1748
1749
1750
1751
1752
1753
1754
1755
1756
1757
1758
1759
1760
1761
1762
1763
1764
1765
1766
1767
1768
1769
1770
1771
1772
1773
1774
1775
1776
1777
1778
1779
1780
1781
1782
1783
1784
1785
1786
1787
1788
1789
1790
1791
1792
1793
1794
1795
1796
1797
1798
1799
1800
1801
1802
1803
1804
1805
1806
1807
1808
1809
1810
1811
1812
1813
1814
1815
1816
1817
1818
1819
1820
1821
1822
1823
1824
1825
1826
1827
1828
1829
1830
1831
1832
1833
1834
1835
1836
1837
1838
1839
1840
1841
1842
1843
1844
1845
1846
1847
1848
1849
1850
1851
1852
1853
1854
1855
1856
1857
1858
1859
1860
1861
1862
1863
1864
1865
1866
1867
1868
1869
1870
1871
1872
1873
1874
1875
1876
1877
1878
1879
1880
1881
1882
1883
1884
1885
1886
1887
1888
1889
1890
1891
1892
1893
1894
1895
1896
1897
1898
1899
1900
1901
1902
1903
1904
1905
1906
1907
1908
1909
1910
1911
1912
1913
1914
1915
1916
1917
1918
1919
1920
1921
1922
1923
1924
1925
1926
1927
1928
1929
1930
1931
1932
1933
1934
1935
1936
1937
1938
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
2036
2037
2038
2039
2040
2041
2042
2043
2044
2045
2046
2047
2048
2049
2050
2051
2052
2053
2054
2055
2056
2057
2058
2059
2060
2061
2062
2063
2064
2065
2066
2067
2068
2069
2070
2071
2072
2073
2074
2075
2076
2077
2078
2079
2080
2081
2082
2083
2084
2085
2086
2087
2088
2089
2090
2091
2092
2093
2094
2095
2096
2097
2098
2099
2100
2101
2102
2103
2104
2105
2106
2107
2108
2109
2110
2111
2112
2113
2114
2115
2116
2117
2118
2119
2120
2121
2122
2123
2124
2125
2126
2127
2128
2129
2130
2131
2132
2133
2134
2135
2136
2137
2138
2139
2140
2141
2142
2143
2144
2145
2146
2147
2148
2149
2150
2151
2152
2153
2154
2155
2156
2157
2158
2159
2160
2161
2162
2163
2164
2165
2166
2167
2168
2169
2170
2171
2172
2173
2174
2175
2176
2177
2178
2179
2180
2181
2182
2183
2184
2185
2186
2187
2188
2189
2190
2191
2192
2193
2194
2195
2196
2197
2198
2199
2200
2201
2202
2203
2204
2205
2206
2207
2208
2209
2210
2211
2212
2213
2214
2215
2216
2217
2218
2219
2220
2221
2222
2223
2224
2225
2226
2227
2228
2229
2230
2231
2232
2233
2234
2235
2236
2237

Contents

Page

Foreword	iv
1 Scope.....	1
2 Normative references	1
3 Terms and definitions.....	1
4 Symbols and abbreviated terms.....	2
5 Principle	2
6 Selection and preparation of the specimen	5
6.1 Test location	5
6.2 Revealing ferritic grain boundaries.....	5
6.3 Revealing austenitic and prior-austenitic grain boundaries	5
7 Characterization of grain size.....	10
7.1 Characterization by an index	10
7.2 Characterization by the intercept method	11
8 Test report.....	14
Annex A (informative) Summary of methods for revealing ferritic, austenitic or prior-austenitic grain boundaries in steels.....	15
Annex B (normative) Determination of grain size — Standard charts taken from ASTM E112	16
Annex C (normative) Evaluation method	31

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 643 was prepared by Technical Committee ISO/TC 17, *Steel*, Subcommittee SC 7, *Methods of testing (other than mechanical tests and chemical analysis)*.

This second edition cancels and replaces the first edition (ISO 643:1983), which has been technically revised.

Steels — Micrographic determination of the apparent grain size

1 Scope

This International Standard specifies a micrographic method of determining apparent ferritic or austenitic grain size in steels. It describes the methods of revealing grain boundaries and of estimating the mean grain size of specimens with unimodal size distribution. Although grains are three-dimensional in shape, the metallographic sectioning plane can cut through a grain at any point from a grain corner, to the maximum diameter of the grain, thus producing a range of apparent grain sizes on the two-dimensional plane, even in a sample with a perfectly consistent grain size.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3785, *Steel — Designation of test piece axes*

ISO 14250, *Steel — Metallographic characterization of duplex grain size and distributions*

ASTM E112, *Standard Test Methods for Determining Average Grain Size*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1

grain

closed polygonal shape with more or less curved sides, which can be revealed on a flat cross-section through the sample, polished and prepared for micrographic examination

A distinction is made between:

3.1.1

austenitic grain

crystal with a face-centered cubic crystal structure which may, or may not, contain annealing twins

3.1.2

ferritic grain

crystal with a body-centered cubic crystal structure which never contains annealing twins¹⁾

1) Ferritic grain size is generally estimated for non-alloy steels with a carbon content of 0,25 % or less. If pearlite islands of identical dimensions to those of the ferrite grains are present, the islands are then counted as ferrite grains.

3.2

index

positive, zero or possibly negative number G which is derived from the mean number m of grains counted in an area of 1 mm^2 of the section of the specimen

NOTE By definition, $G = 1$ where $m = 16$; the other indices are obtained by the formula

$$m = 8 \times 2^G$$

3.3

intercept

$\bar{N}$

number of grains intercepted by a test line, either straight or curved

See Figure 1.

NOTE Straight test lines will normally end within a grain. These end segments are counted as 1/2 an interception. $\bar{N}$ is the average of a number of counts of the number of grains intercepted by the test line applied randomly at various locations. $\bar{N}$ is divided by the true line length, L_T , usually measured in millimetres, in order to obtain the number of grains intercepted per unit length, $\bar{N}_L$.

3.4

intersection

$\bar{P}$

number of intersection points between grain boundaries and a test line, either straight or curved

See Figure 1.

NOTE $\bar{P}$ is the average of a number of counts of the number of grain boundaries intersected by the test line applied randomly at various locations. $\bar{P}$ is divided by the true line length, L_T , usually measured in millimetres, in order to obtain the number of grain boundary intersections per unit length, $\bar{P}_L$.

4 Symbols and abbreviated terms

The symbols used are given in Table 1.

5 Principle

The grain size is revealed by micrographic examination of a polished section of the specimen prepared by an appropriate method for the type of steel and for the information sought.

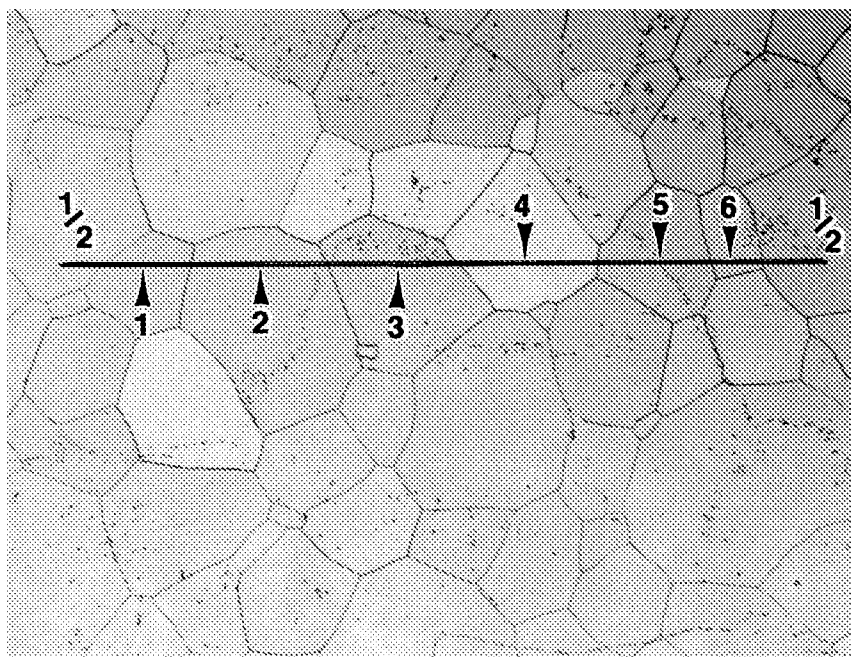
NOTE If the order or the International Standard defining the product does not stipulate the method of revealing the grain, the choice of this method is left to the manufacturer.

This average size is characterized either

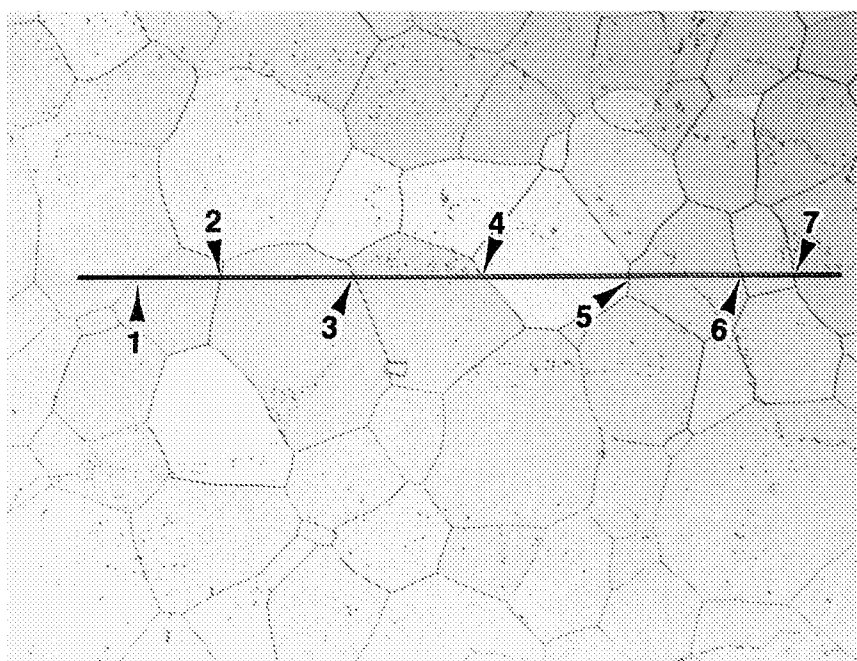
a) by an index obtained

- usually by comparison with standard charts for the measurement of grain size;
- or by counting to determine the average number of grains per unit area;

b) or by the mean value of the intercepted segment.



Interception, N , counts for a straight line on a single-phase grain structure where the arrows point to 6 intercepts and two line segments ending within grain ($2 \times 1/2 = 1 N$) and $N = 7$



Intersection, P , counts for a straight test line placed over a single-phase grain structure where the arrows point to 7 intersection points and $P = 7$

Figure 1 — Examples of intersection, P , and interception, N

Table 1 — Symbols

Symbols	Definition	Value
$\bar{a}$	Mean area of grain in square millimetres	$\bar{a} = \frac{1}{m}$
A_F	Apparent area of the test figure in square millimetres	—
$\bar{d}$	Mean grain diameter in millimetres	$\bar{d} = \frac{1}{\sqrt{m}}$
D	Diameter of the circle on the ground glass screen of the microscope or on a photomicrograph enclosing the image of the reference surface of the test piece	79,8 mm (area = 5 000 mm ²)
g	Linear magnification (to be noted as a reference) of the microscopic image	In principle 100
G	Equivalent index of grain size	—
K	Conversion factor from linear magnification $\times g$ to linear magnification $\times 100$	$K = \frac{g}{100}$
l	Mean lineal intercept length, generally expressed in millimetres	$l = 1/\bar{N}_L = 1/\bar{P}_L$
L	Length of the test line divided by the magnification, in millimetres	—
L_T	True length of the test line divided by the magnification, in millimetres	—
m	Number of grains per square millimetre of test piece surface in the area examined	$m = 2 n_{100}$ (magnification $\times 100$) $m = 2 K^2 n_g$ (magnification $\times g$)
M	Number of the closest standard chart picture where g is not 100.	—
n_g	Total equivalent number of grains examined on the image of diameter D (with a magnification $\times g$)	—
n_1	Number of grains completely inside the circle of diameter D	—
n_2	Number of grains intersected by the circle of diameter D	—
n_{100}	Total equivalent number of grains examined on the image of diameter D (with magnification $\times 100$)	$n_{100} = n_1 + \frac{n_2}{2}$
$\bar{N}$	Mean number of grains intercepted per unit length L	—
$\bar{N}_L$	Mean number of grains intercepted per unit length of the line	$\bar{N}_L = \bar{N} / L_T$
N_x	Number of intercepts per millimetre in the longitudinal direction ^a	—
N_y	Number of intercepts per millimetre in the transverse direction ^a	—
N_z	Number of intercepts per millimetre in the perpendicular direction ^a	—
$\bar{P}$	Mean number of counts of the number of grain boundaries intersected by the test line applied randomly at various locations	—
$\bar{P}_L$	Mean number of grain boundary intersections per unit length of test line	$\bar{P}_L = \bar{P} / L_T$
^a The method for designating the direction conforms to ISO 3785.		

6 Selection and preparation of the specimen

6.1 Test location

If the order, or the International Standard defining the product, does not specify the number of specimens and the point at which they are to be taken from the product, these are left to the manufacturer, although it has been shown that precision of grain size determination increases the higher the number of specimens assessed. Therefore, it is recommended that two or more sections be assessed. Care shall be taken to ensure that the specimens are representative of the bulk of the product (i.e., avoid heavily deformed material such as that found at the extreme end of certain products or where shearing has been used to remove the specimen etc.). The specimens shall be polished in accordance with the usual methods.

Unless otherwise stated by the product standard or by agreement with the customer, the polished face of the specimen shall be longitudinal, i.e., parallel to the principal axis of deformation in wrought products. Measurements of the grain size on a transverse plane will be biased if the grain shape is not equiaxial.

6.2 Revealing ferritic grain boundaries

The ferritic grains shall be revealed by etching with nital (ethanolic 2 % to 3 % nitric acid solution), or with an appropriate reagent.

6.3 Revealing austenitic and prior-austenitic grain boundaries

6.3.1 General

In the case of steels having a single-phase or two-phase austenitic structure (delta ferrite grains in an austenitic matrix) at ambient temperature, the grain shall be revealed by an etching solution. For single phase austenitic stainless steels, the most commonly used chemical etchants are glyceric acid, Kalling's reagent (No. 2) and Marble's reagent. The best electrolytic etch for single or two-phase stainless steels is aqueous 60 % nitric acid at 1,4 V d.c. for 60 s to 120 s, as it reveals the grain boundaries but not the twin boundaries. Aqueous 10 % oxalic acid, 6 V d.c., up to 60 s, is commonly used but is less effective than electrolytic 60 % HNO_3 .

For other steels, one or other of the methods specified below shall be used depending on the information required.

- "Bechet-Beaujard" method by etching with aqueous saturated picric acid solution (see 6.3.2);
- "Kohn" method by controlled oxidation (see 6.3.3);
- "McQuaid-Ehn" method by carburization (see 6.3.4);
- grain boundary sensitization method (see 6.3.7);
- other methods specially agreed upon when ordering.

NOTE The first three methods are for prior-austenitic grain boundaries while the others are for austenitic Mn or austenitic stainless, see Annex A.

If comparative tests are carried out for the different methods, it is essential to use the same heat treatment conditions. Results may vary considerably from one method to the other.

6.3.2 “Bechet-Beaujard” method by etching with aqueous saturated picric acid solution

6.3.2.1 Field of application

This method reveals austenitic grains formed during heat treatment of the specimen. It is applicable to specimens which have a martensitic or bainitic structure. For this etch to work, there shall be at least 0,005 % P.

6.3.2.2 Preparation

The Bechet-Beaujard etchant is normally used on a heat-treated steel specimen. Normally, no subsequent heat treatment is necessary if the specimen has a martensitic or bainitic structure. If this is not the case, heat treatment is necessary.

If the conditions for treating the test piece are not provided for by the International Standard defining the product and there is no specification to the contrary, the following conditions shall be applied in the case of heat-treated structural carbon steels and low-alloy steels:

- 1,5 h at $(850 \pm 10)^\circ\text{C}$ for steels whose carbon content is greater than 0,35 %;
- 1,5 h at $(880 \pm 10)^\circ\text{C}$ for steels whose carbon content is less than or equal to 0,35 %.

After this treatment, the test piece shall be quenched into water or oil.

6.3.2.3 Polishing and etching

A flat specimen surface shall be polished for micrographic examination. It shall be etched for an adequate period of time by means of an aqueous solution saturated with picric acid together with at least 0,5 % sodium alkylsulfonate or another appropriate wetting agent.

NOTE The period of etching may vary from a few minutes to more than one hour. Heating of the solution to 60°C may improve the etching action and reduce etching time.

Several successive etching and polishing operations are sometimes necessary to ensure a sufficient contrast between the grain boundaries and the general base of the specimen. In the case of through-hardened steel, tempering may be carried out before selecting the specimen.

WARNING: When heating solutions containing picric acid, caution shall be taken to avoid the solution boiling dry as picric acid can become explosive.

6.3.2.4 Result

The prior-austenite grain boundaries shall be immediately apparent on microscopic examination.

6.3.3 “Kohn” method by controlled oxidation

6.3.3.1 Field of application

This method shows up the austenitic grain pattern formed by preferential oxidation of the boundaries during austenization at the temperature of a given heat treatment.

6.3.3.2 Preparation

One surface of the specimen shall be polished. The rest of its surface shall not show any traces of oxide. The specimen shall be placed in a laboratory furnace in which either a vacuum of 1 Pa is attained or an inert gas is circulated (e.g. purified argon). Heat treat the specimen in accordance with the austenitizing procedure specified by the customer, or as defined by the International Standard governing the product.

At the end of this specified heating period, air shall be introduced into the furnace for a period of 10 s to 15 s.

The specimen shall then be water-quenched. The specimen can usually be directly examined using a microscope.

NOTE 1 The oxidation method can be done without the inert atmosphere.

NOTE 2 The oxide adhering to the previously polished surface should be removed by light polishing with a fine abrasive, taking care that the oxide network which has formed on the grain boundaries is retained; then the polishing should be completed by the usual methods. The specimen should then be etched using Vilella's reagent:

- picric acid 1 g
- hydrochloric acid 5 ml
- ethanol 100 ml

6.3.3.3 Result

The preferential oxidation of the boundaries shows up the pattern of austenitic grains.

If the preparation is effected correctly, no oxide globules should appear at the grain boundaries.

In certain cases, it may be necessary to use oblique illumination, or DIC (Differential Interference Contrast) methods, to show up the boundaries in better relief.

6.3.4 “McQuaid-Ehn” method by carburization at 925 °C

6.3.4.1 Field of application

This is a method specifically for carburizing steels and shows up austenitic grain boundaries formed during carburization of these steels. It is not usually suitable for revealing grains actually formed during other heat treatments.

NOTE The “mock carburizing” procedure may also be used. The specimen is subjected to the same thermal treatment but without a carbon-rich atmosphere. It is then heat-treated as the product would be treated. The Bechet-Beaujard reagent is used to reveal the grain boundaries, see 6.3.2.

6.3.4.2 Preparation

The specimens shall be free from any trace of decarburization or of surface oxidation. Any prior treatment, either cold, hot, mechanical, etc., may have an effect on the shape of the grain obtained; the product specification shall state the treatments to be carried out before determination in cases where it is advisable to take into account these considerations.

After carburizing, the specimen must be cooled at a rate slow enough to precipitate cementite at the grain boundaries in the hypereutectoid surface region of the carburized specimen.

Carburization shall be achieved by maintaining the specimen at $(925 \pm 10)^\circ\text{C}$ for 6 h. This is generally done by keeping the carburizing chamber at $(925 \pm 10)^\circ\text{C}$ for 8 h, including a pre-heating period. In most cases, a carburized layer of approximately 1 mm is obtained. After carburizing, cool the specimen at a rate slow enough to ensure that the cementite is precipitated at the grain boundaries of the hypereutectoid zone of the carburized layer.

Fresh carburizing compound shall be used each time.

6.3.4.3 Specimen preparation

The carburized specimen shall be sectioned normally to its surface. One of the sections shall be prepared for micrographic examination and etched using either a) or b).

a) "Le Chatelier and Igewski" reagent (alkaline sodium picrate):

— picric acid	2 g
— sodium hydroxide	25 g
— water	100 ml

Use this reagent by immersion at 100 °C, for at least 1 min, or at room temperature by means of electrolytic etching 6 V d.c. for 60 s.

b) Nital:

— nitric acid	2 ml to 5 ml
— ethanol	to make up to 100 ml

Other reagents may be used as long as the same results are obtained.

6.3.4.4 Result

The prior-austenite grain boundaries in the hypereutectoid carburized surface layer will be delineated by proeutectoid cementite.

6.3.5 Proeutectoid ferrite method

NOTE Guidelines for the use of this method depending on the microstructure of the steel product are given in Annex A.

6.3.5.1 Principle

This method is suitable for carbon steel with about 0,25 % to 0,6 % carbon and for low-alloy steels such as manganese-molybdenum, 1 % chromium, 1 % chromium-molybdenum and 1,5 % nickel-chromium. The prior-austenitic grain boundaries are revealed as a network of proeutectoid ferrite.

6.3.5.2 Preparation

Use the austenizing conditions as given in the product standard. In the case of carbon or other low hardenability steel, either air cool, furnace cool or partially transform isothermally the test pieces in such a manner as to outline the austenitic grain boundaries with ferrite.

In the case of alloy steels, after austenitizing, partially transform isothermally the test pieces at an appropriate temperature within the range 650 °C to 720 °C and then water quench.

NOTE 1 The time required for transformation will vary according to the steel, but usually sufficient ferrite has precipitated in 1 min to 5 min, although longer times, up to about 20 min, can sometimes be required.

NOTE 2 For alloy steels, a test piece 12 mm × 6 mm × 3 mm is suitable to obtain uniform transformation during the isothermal treatment.

6.3.5.3 Polishing and etching

Section, polish and etch the test pieces for micrographic examination. Etch the test pieces with a suitable etchant such as hydrochloric acid and picric acid (Vilellas' reagent).

6.3.6 Bainite or gradient-quench method

NOTE Guidelines for the use of this method depending on the microstructure of the steel product are given in Annex A.

6.3.6.1 Principle

This method is suitable for steels of approximately eutectoid composition, i.e., having a carbon content of 0,7 % by mass or higher. The boundaries of the prior-austenitic grains are revealed by a network of fine pearlite or bainite outlining the martensite grains.

6.3.6.2 Preparation

Heat the test piece to a temperature not more than 30 °C above A_{C3} (i.e., the temperature at which ferrite completes its transformation to austenite during heating) to ensure full austenitization.

Cool the specimen at a controlled rate to produce a partially hardened structure of fine pearlite or bainite outlining the martensite grains.

This structure may be produced in one of the following ways:

- a) by completely quenching in water or oil, as appropriate, a bar of cross-sectional dimensions such that it will fully harden at the surface but only partially harden in the centre;
- b) by gradient quenching a length of bar, 12 mm to 25 mm diameter or square, by immersing it in water for a part of the length only.

Then polish and etch.

6.3.7 Sensitization of austenitic stainless and manganese steels

The grain boundaries may be developed through precipitation of carbides by heating within the sensitizing temperature range, 482 °C to 704 °C (900 °F to 1 300 °F). Any suitable carbide-revealing etchant can be used.

NOTE This method should not be used in case of very low carbon contents in austenitic grades.

6.3.8 Other methods for revealing prior-austenitic grain boundaries

For certain steels, after simple heat treatment (annealing or normalizing, quenching and tempering, etc.), the pattern of the austenitic grains may appear in the following forms under micrographic examination: a network of proeutectoid ferrite surrounding pearlite grains, a network of very fine pearlite surrounding martensite grains, etc. The austenitic grain may also be revealed by thermal etching under vacuum (not necessarily followed by oxidation). The product specification shall mention these simplified methods²⁾ in these cases.

2) Amongst these methods are the following:

- precipitation on the grain boundaries during cooling;
- gradient quenching method, etc.

7 Characterization of grain size

7.1 Characterization by an index

7.1.1 Formulae

The index is defined in 3.2 by the formula

$$m = 8 \times 2^G \quad (1)$$

This formula may be stated as

$$G = \frac{\log m}{\log 2} - 3 \quad (2a)$$

or

$$G = \frac{\log m}{0,301} - 3 \quad (2b)$$

7.1.2 Assessment by comparison with standard grain size charts

The image examined on the screen (or on a photomicrograph) is compared with a series of standard charts³⁾ or overlays (eye-piece graticules designed for grain size measurement can be used providing these are traceable to National or International standards). The standard charts at a magnification of $\times 100$ are numbered from 00 to 10 so that their number is equal to the index G .

The standard chart with the grain size closest to that of the examined fields of the specimen can then be determined. A minimum of three randomly-selected fields shall be assessed on each specimen.

Where the magnification g of the image on the screen or photomicrograph is not $\times 100$, the index G shall be equal to the number M of the closest standard chart, modified as a function of the ratio of the magnifications:

$$G = M + 6,64 \times \log \frac{g}{100} \quad (3)$$

Table 2 gives the relationship between the indices for the usual magnifications.

Table 2 — Relationship between indices for the usual magnifications

Magnification of the image	Index of metal grain for an image identified on a standard chart No.							
25	− 3	− 2	− 1	0	1	2	3	4
50	− 1	0	1	2	3	4	5	6
100	1	2	3	4	5	6	7	8
200	3	4	5	6	7	8	9	10
400	5	6	7	8	9	10	11	12
500	5,6	6,6	7,6	8,6	9,6	10,6	11,6	12,6
800	7	8	9	10	11	12	13	14

3) These standard charts are defined in ASTM E112 [(plates IA and IB) (Annex B)]. The standard charts selected should be adhered to throughout the whole of the examination.

7.1.3 Planimetric method

The evaluation method is defined in Annex C.

7.1.4 Estimation of the index

Whether the estimate is carried out by comparison or by count, the accuracy obtained is rarely greater than a half-unit. The index shown shall be rounded to a whole number.

7.2 Characterization by the intercept method

Count the number of grains intercepted, N , or the number of grain boundary intersections, P , with a test line of known length on a projection screen, on a reticle, on a television-type monitor or on a photomicrograph of a representative of the bulk of the specimen at a known magnification, g .

The measuring line may be straight or circular. The measuring grid in Figure 2 shows the types of recommended measuring line.

The grid shall be applied only once to the field examined. It is applied at random to an adequate number of fields to have a valid count.

The dimensions in millimetres of the three circles shall be:

Diameter	Circumference
79,58	250,0
53,05	166,7
26,53	83,3
Total	500,0

7.2.1 Linear intercept segment method

7.2.1.1 Figure 2 shows a test pattern that can be used to measure grain size by the intercept method. The three concentric circles have a total line length of 500 mm. A circular test grid averages out variations in the shape of equiaxed grains and avoids the problem of lines ending within grains. Figure 2 also has four straight lines; two oriented diagonally, one vertically and one horizontally. Each diagonal line has a length of 150 mm while the horizontal and vertical lines are each 100 mm long. The straight lines will also average out variations in the shape of equiaxed grains. Alternatively, if the degree of grain elongation is of interest, grain counts can be made using only the vertical and horizontal lines (separately) when they are aligned so that the horizontal line is parallel to the deformation axis (and the vertical line is then perpendicular to the deformation axis) on a longitudinally-oriented polished plane [see 7.2.3, c)].

The magnification shall be selected so that at least 50 intercepts are obtained in any one field. At least five randomly selected fields shall be assessed with a total number of intercepts of at least 250.

NOTE If the grain size of the specimen requires the magnification to be changed in order to achieve the required number of intercepts, the length of the measuring lines can also be varied providing that the orientation of the measuring lines is arranged to take account of the effects of anisotropy.

The following rules apply to interception and intersection counts of single-phase grain structures using straight test lines.

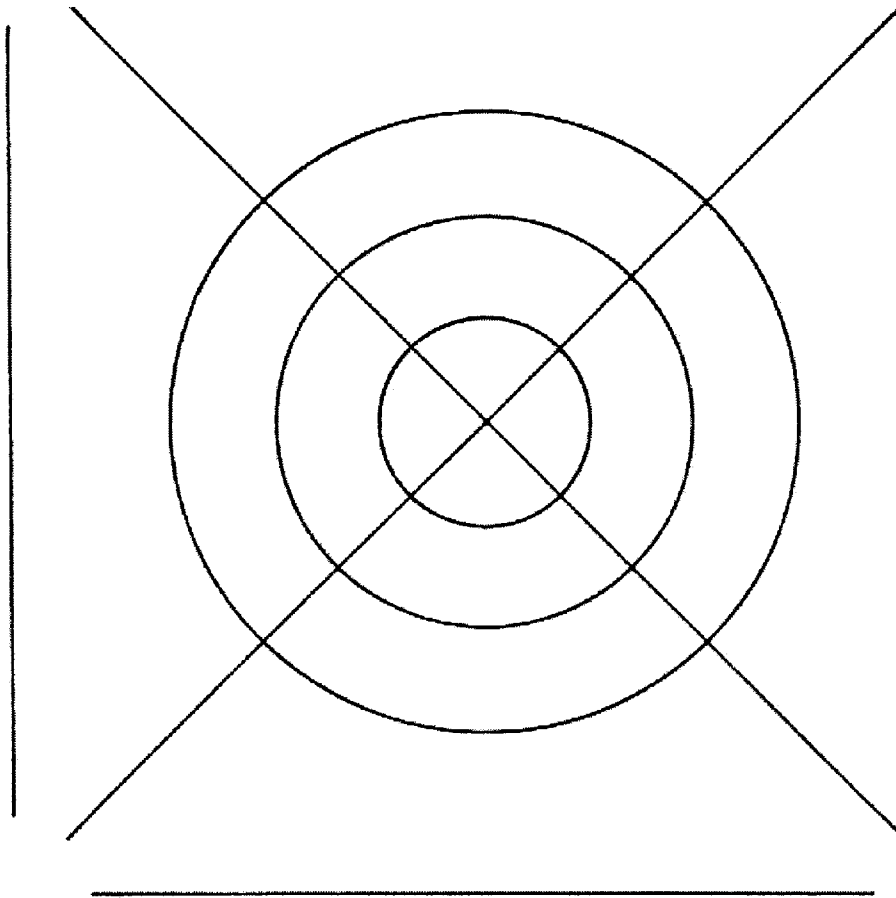


Figure 2 — Recommended measurement grid for the intercept segment method

7.2.1.2 When the number of intercepted grains, N , is counted:

- if a test line goes through a grain, N is 1;
- if a test line terminates within a grain, N is 0,5;
- if a test line is tangential to a grain boundary, N is 0,5.

7.2.1.3 When the number of grain boundary intersections, P , is counted:

- if a test line passes through a grain boundary, P is 1;
- if a test line is tangential to a grain boundary, P is 1;
- if a test line intersects a triple point, P is 1,5

NOTE The “Snyder-Graff” method, described in Annex C, represents a linear intercept method for tool steel (high-speed steels).

7.2.2 Circular intercept segment method

The pattern of circles shown in Figure 2 is recommended.

The measuring line consists either of a set of three concentric circles as shown in Figure 2 or of one single circle.

The total length of the three circles of the recommended grid shown in Figure 2 is 500 mm. The magnification or diameter of the circle shall be selected so that there are 40 to 50 intercepts when the measurement grid is superposed on the field to be examined.

In the case of a single circle, the largest circle with a circumference of 250 mm is used. In this case, the magnification to be used shall enable at least 25 intercepts to be counted.

The circular intercepted segment method tends to give slightly high intercepted segment values and thus a slightly low number of intersections. In order to compensate for this, the intersections caused by a triple point shall be counted as two intersections instead of 1,5 as is the case with the linear intercepted segment method.

7.2.3 Assessment of results

Counts of the number of intercepts, N , or intersections, P , are made on a number of fields selected at random. The mean value of the number of intercepts, $\bar{N}$, or intersections, $\bar{P}$, is calculated.

If L_T is the true length of the test line then

$$\bar{N}_L = \bar{N} / L_T \text{ and } \bar{P}_L = \bar{P} / L_T$$

For the case of non-equiaxed grain structures, counts can be made of the number of interceptions, N , or intersections, P , of the grains or grain boundaries, with straight test lines oriented parallel to the three principal directions. These three directions can be found on any two of the three principal test planes (longitudinal, transverse and planar).

The mean number of intercepts per millimetre, $\bar{N}_L$, or the mean number of intersections per millimetre, $\bar{P}_L$, is determined from the cube root of the product of the three measurements:

$$\bar{N}_L = (\bar{N}_{Lx} \times \bar{N}_{Ly} \times \bar{N}_{Lz})^{1/3} \text{ and } \bar{P}_L = (\bar{P}_{Lx} \times \bar{P}_{Ly} \times \bar{P}_{Lz})^{1/3}$$

where the bars above the quantities indicate that they are the means (averages) of a number of measurements and x, y, and z indicate the principal directions (longitudinal, transverse and planar).

- a) Grains of different size indices: In certain cases, the specimen examined may include grains belonging to two or more different systems of size indices. This can be recognized by the presence of several grains of greatly differing dimensions from those of the whole, e.g., see ISO 14250.
- b) Twin grains: Unless otherwise specified, these are counted as a single grain, that is, twin boundaries are ignored (see Figure 3).
- c) Non-equiaxed grains: The grain shape can be expressed by dividing the mean lineal intercept length in the deformation direction by the mean lineal intercept length perpendicular to the deformation direction using a longitudinally oriented test specimen. This is referred to as the grain elongation ratio, or the anisotropy index.
- d) Modern methods of grain size measurement: Such as ultrasonic methods, automatic image analysis, etc., can be used to measure grain size of applicable materials providing that the accuracy of the methods has previously been proven by an extensive cross correlation.

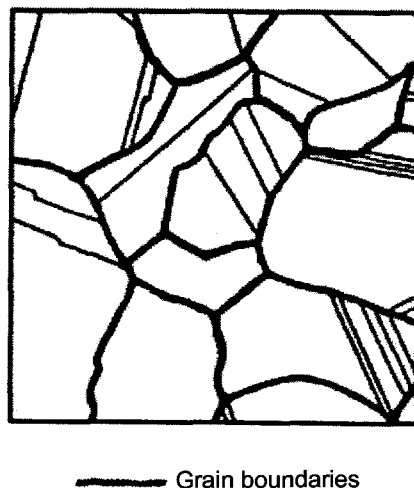


Figure 3 — Evaluation of number of grains (twin grains)

8 Test report

The test report shall contain the following information:

- a) grade of the steel examined;
- b) type of grain determined;
- c) method used, operating conditions, method of evaluation (i.e., manual or automatic image analysis);
- d) grain size index or the value of the mean segment.

Annex A

(informative)

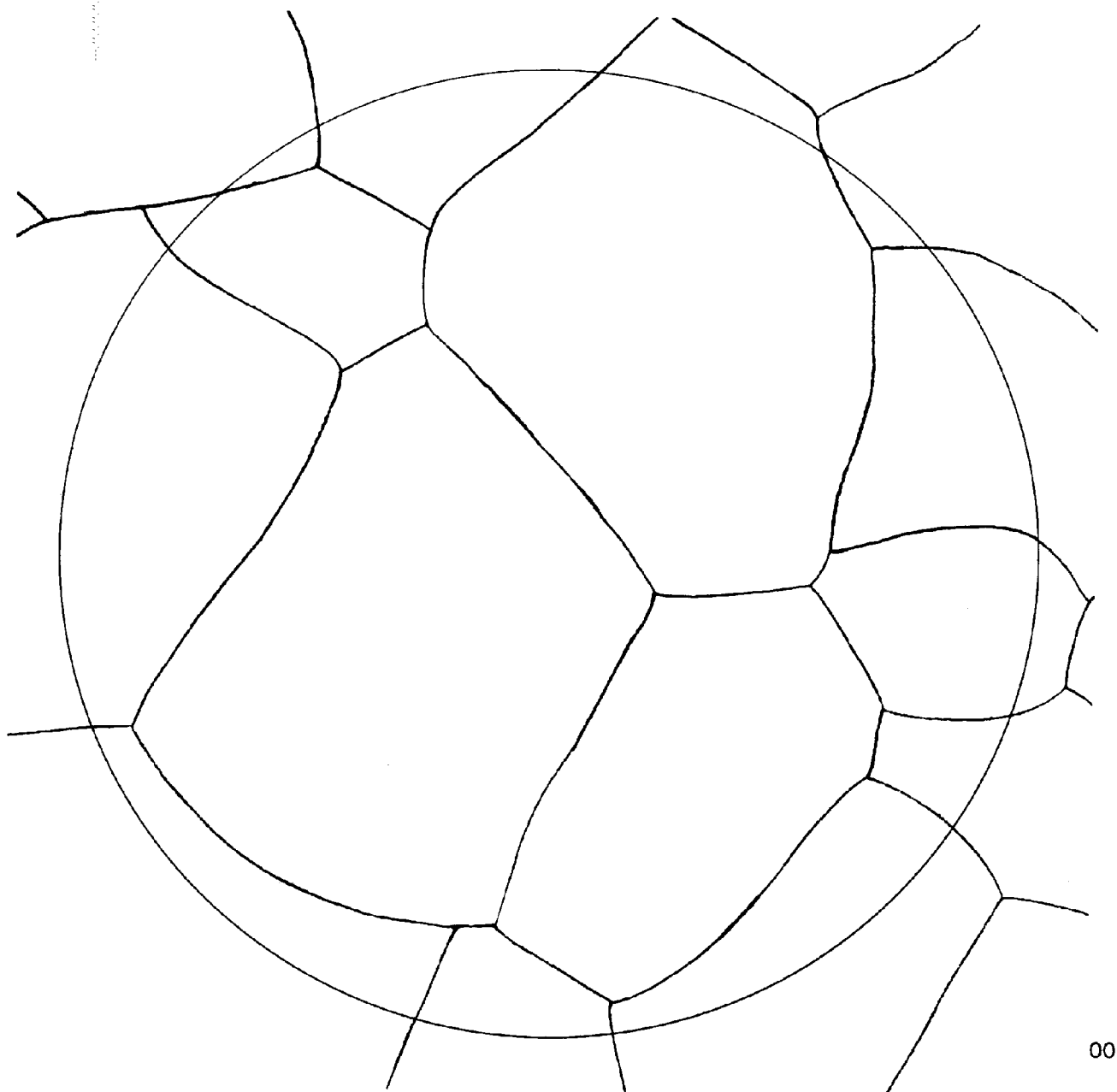
Summary of methods for revealing ferritic, austenitic or prior-austenitic grain boundaries in steels

Method	Applicable steels
The "Bechet-Beaujard" etch method (see 6.3.2)	Steels with martensitic, tempered martensitic or bainitic structures that contain $\geq 0,005$ % phosphorus
The "Kohn" oxidation method (see 6.3.3)	Carbon and low-alloy steels
The "McQuaid-Ehn" carburizing method (see 6.3.4)	Carburizing steels
The mock carburizing method (see 6.3.4)	
The proeutectoid ferrite delineation method (see 6.3.5)	Coarse-grained carbon steels with between 0,26 % and 0,6 % carbon; also low-alloy steels such as Mn-Mo, 1 % Cr, 1 % Cr-Mo and 1,5 % Cr-Ni
The bainite or gradient quench method (see 6.3.6)	Coarse-grained steels of approximately eutectoid carbon content, i.e., 0,7 % to 0,8 % carbon
The grain boundary sensitization method (see 6.3.7)	Unstabilized austenitic or duplex stainless steels with a carbon content $> 0,025$ % ^a
The quenching and tempering method (see 6.3.8)	Carbon steels
Direct etching using a suitable reagent (see 6.2)	All single-phase steels
^a Austenitic Mn steels will precipitate a fine carbide aggregate at the grain boundaries when aged between 550 °C and 600 °C.	

Annex B
(normative)

Determination of grain size — Standard charts taken from ASTM E112⁴⁾

Plate 1A — Untwinned grains (flat etch) × 100



4) The charts are reproduced, with permission, from ASTM E112. For a comparison chart showing the grain size, please contact ASTM, 100 Barr Harbor Drive, Philadelphia, PA 19428-3914, USA (refer to adjunct No. ADJ 12-501120-10).

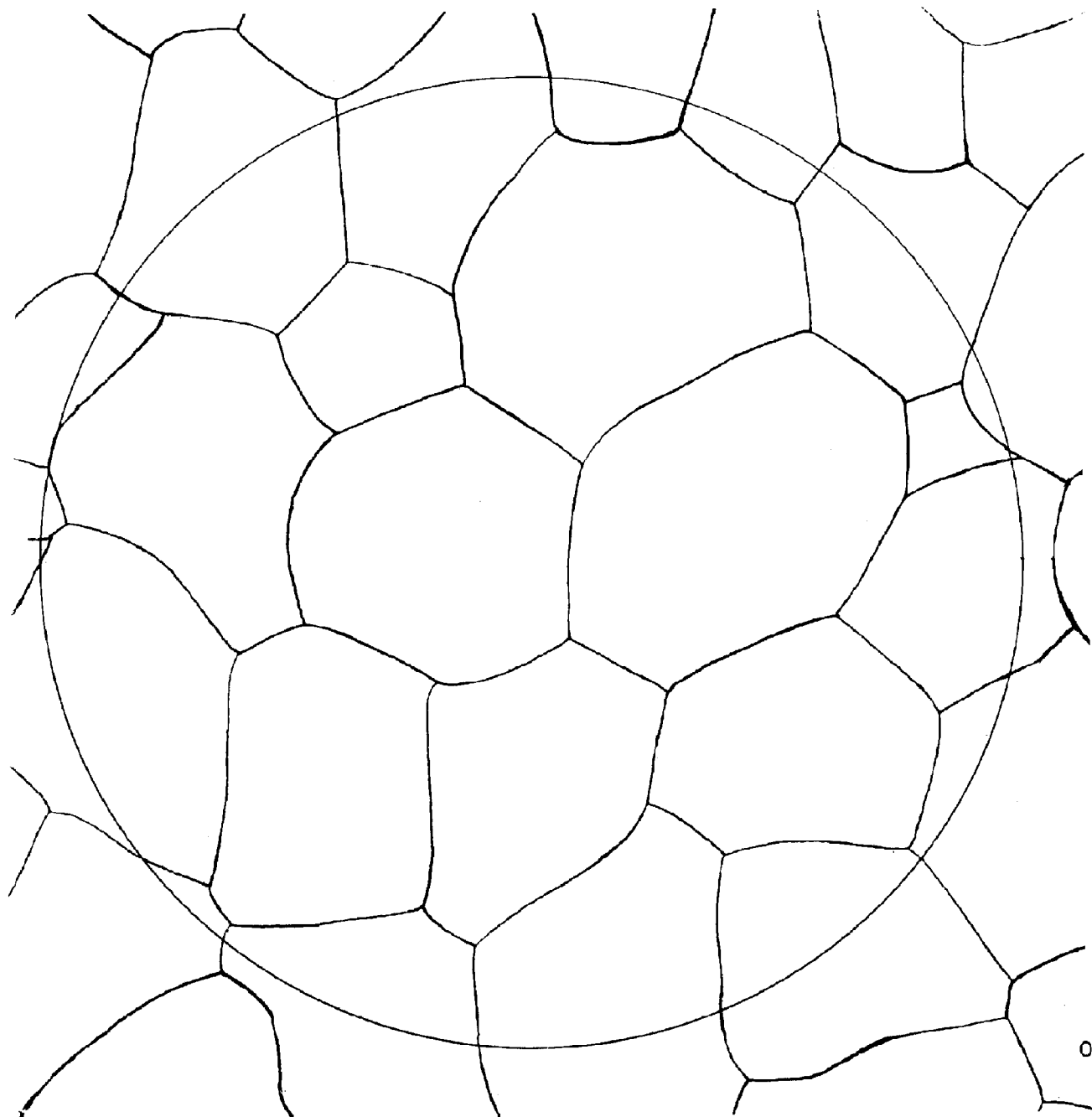
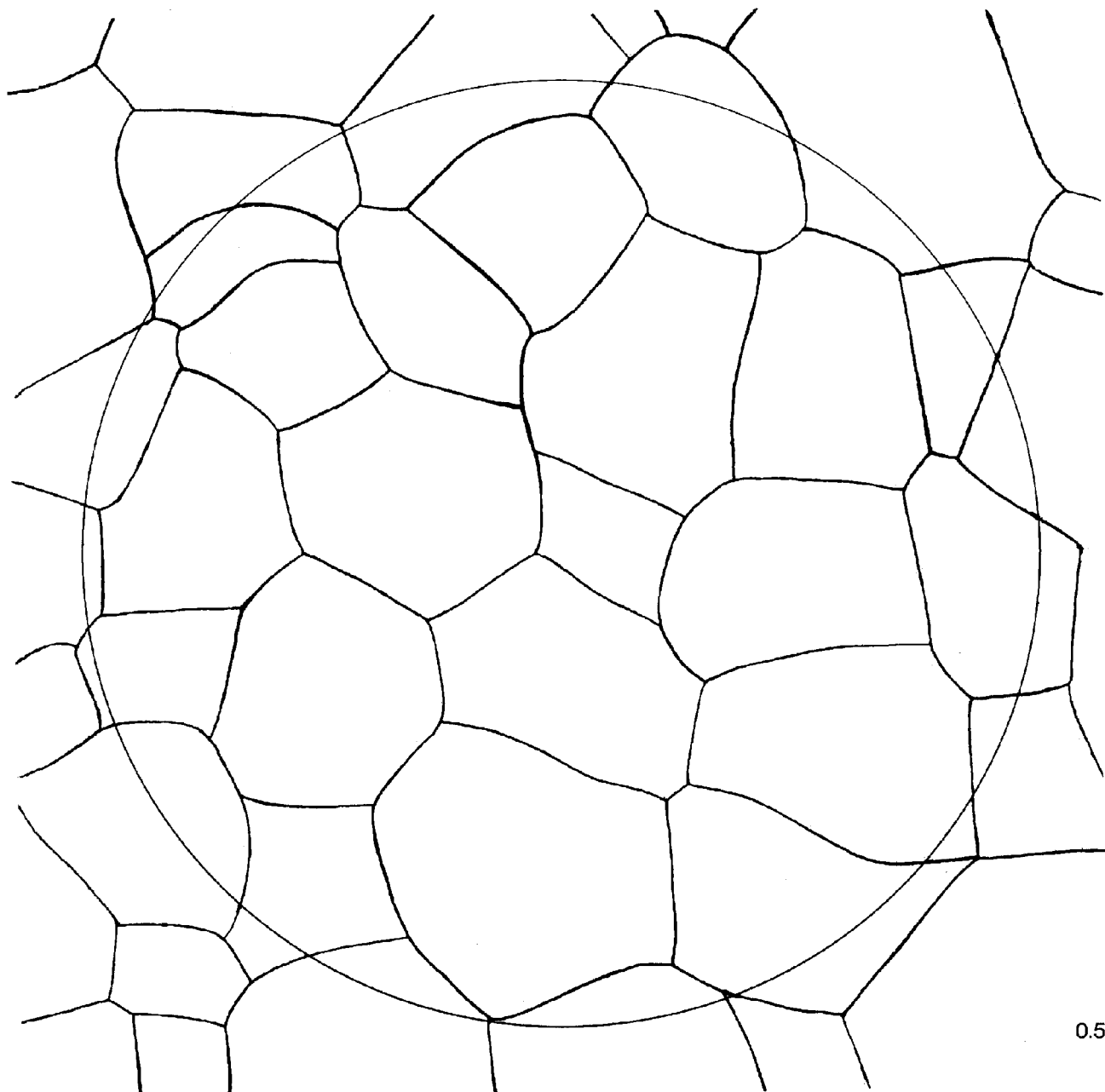
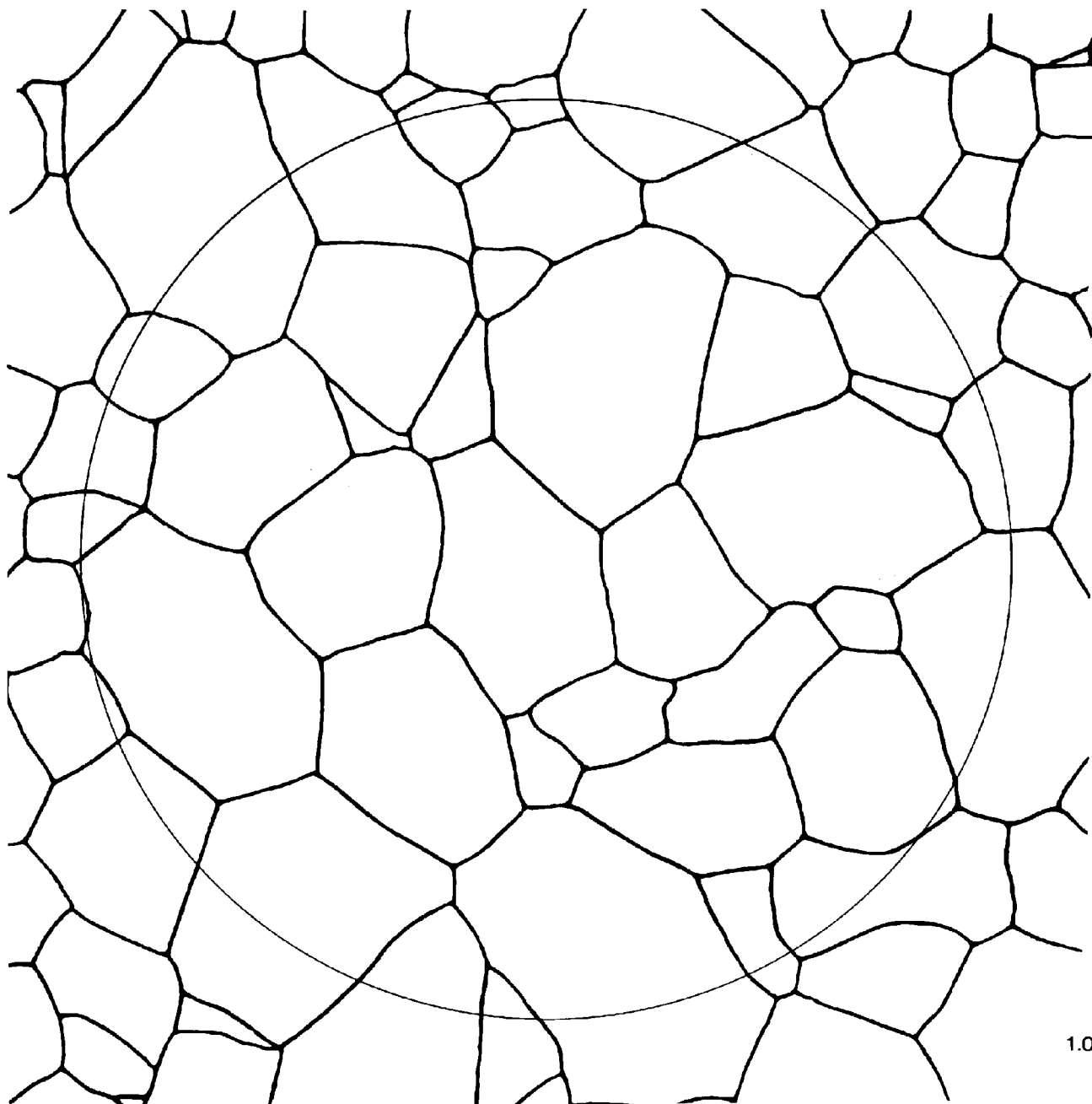
Plate 1A (*continued*) — Untwinned grains (flat etch) $\times 100$ 

Plate 1A (*continued*) — Untwinned grains (flat etch) $\times 100$

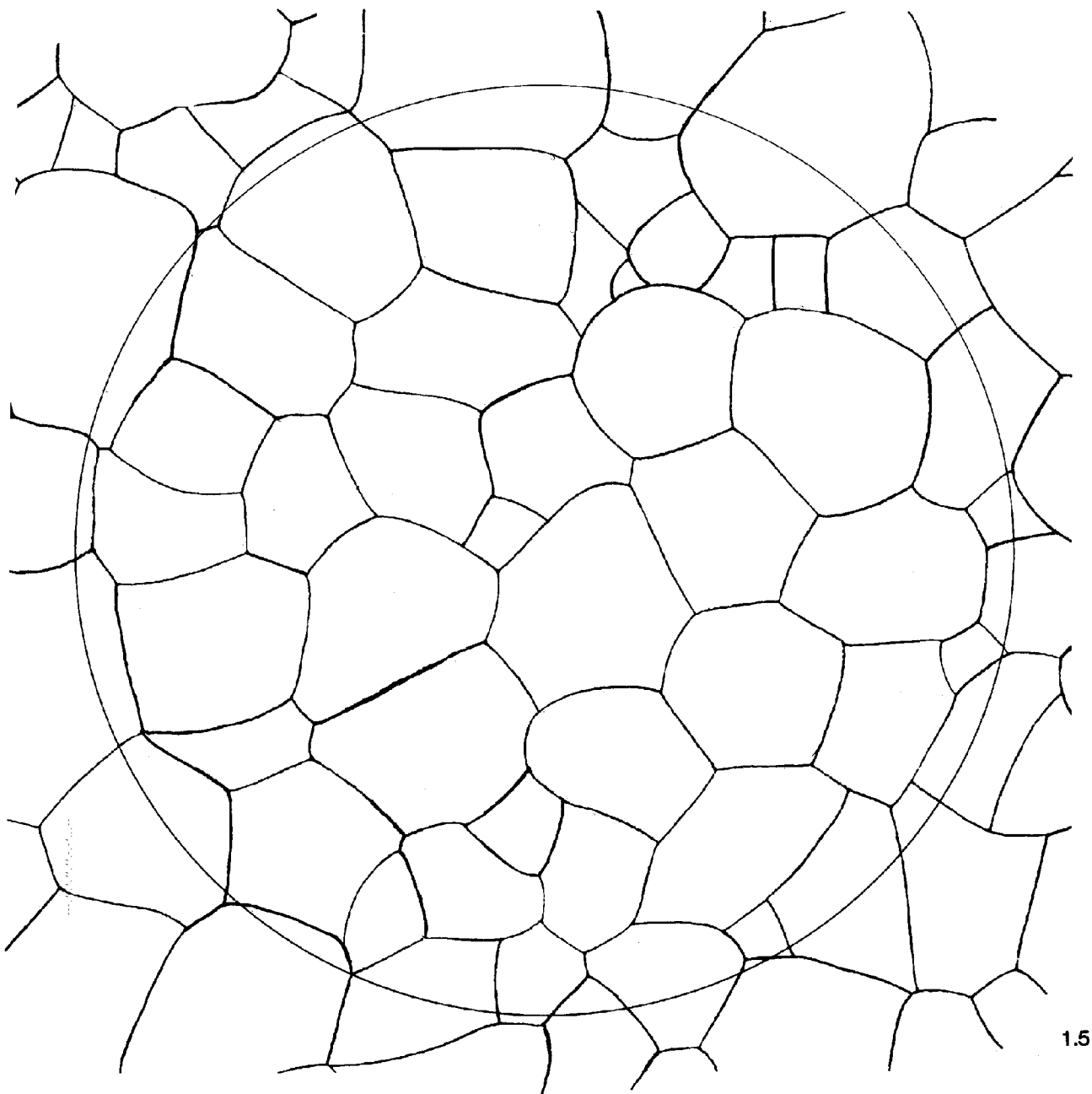


0.5

Plate 1A (continued) — Untwinned grains (flat etch) $\times 100$ 

1.0

Plate 1A (*continued*) — Untwinned grains (flat etch) $\times 100$



1.5

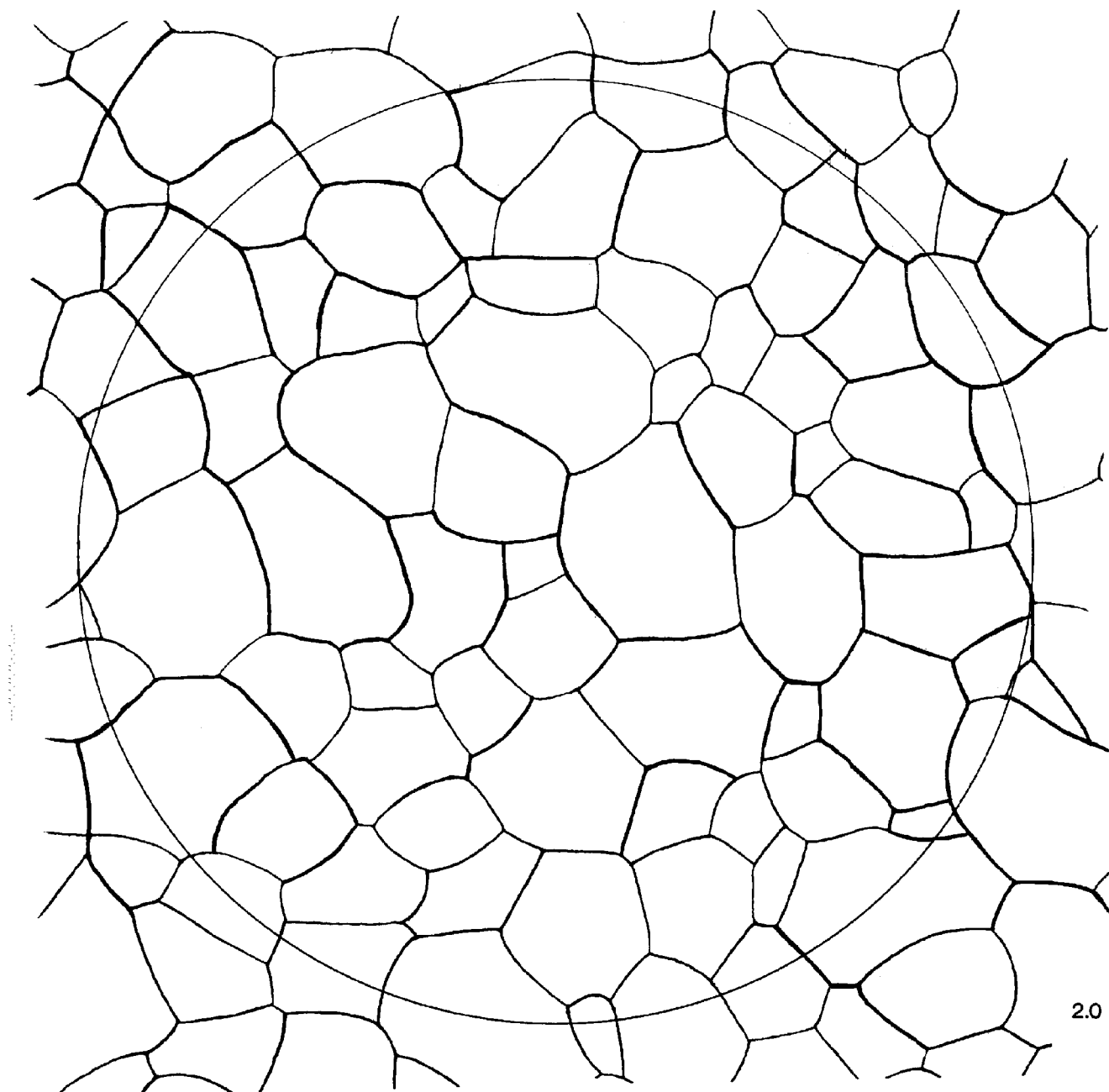
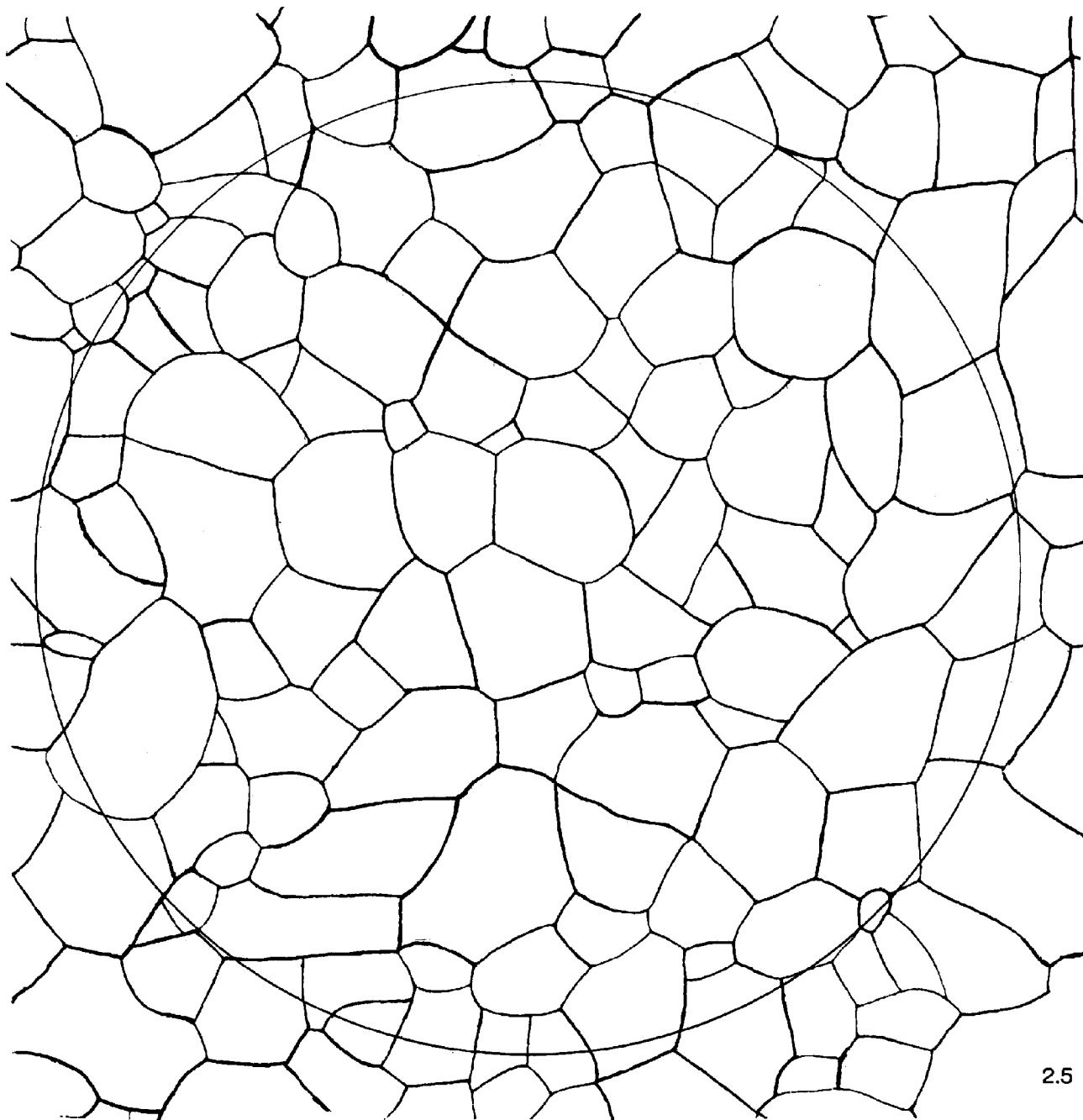
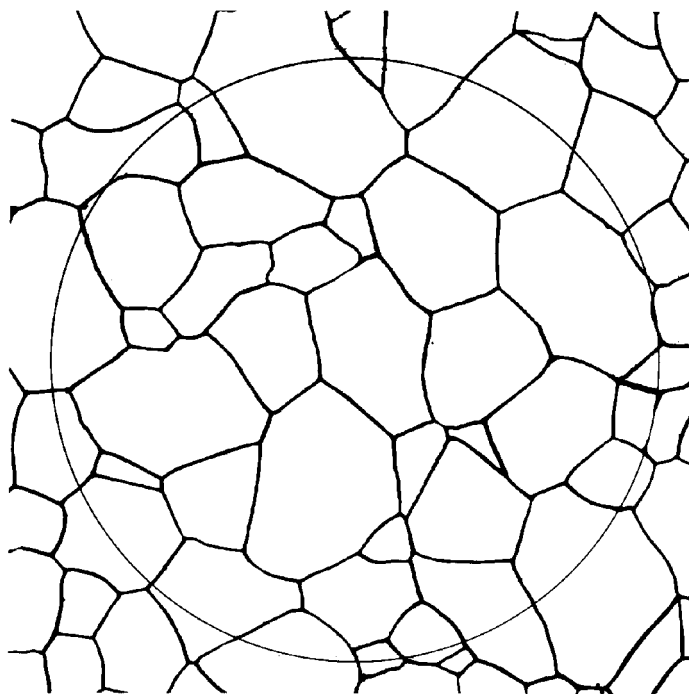
Plate 1A (continued) — Untwinned grains (flat etch) $\times 100$ 

Plate 1A (*continued*) — Untwinned grains (flat etch) $\times 100$

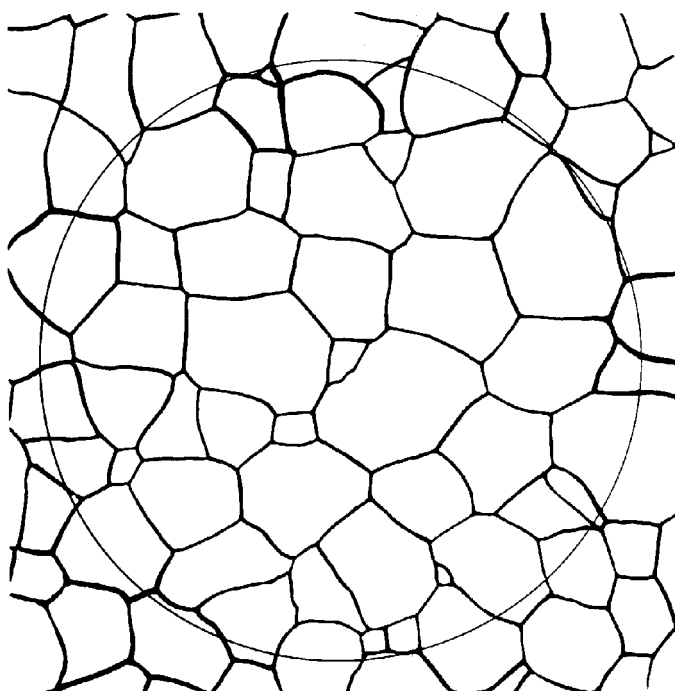


2.5

Plate 1B — Untwinned grains (flat etch) × 100

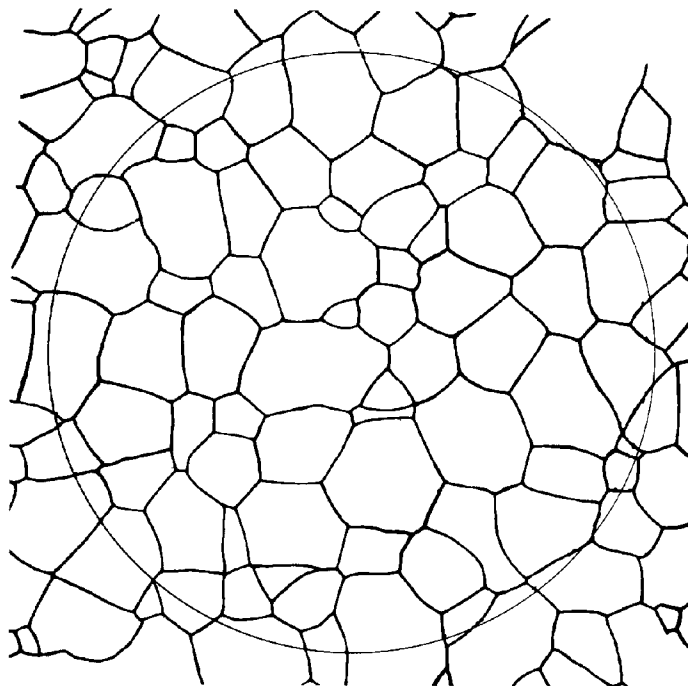


3.0

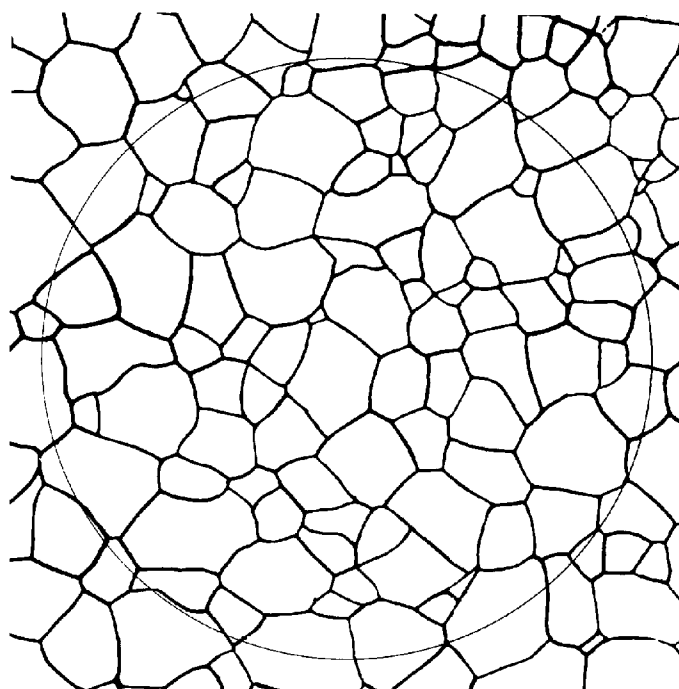


3.5

Plate 1B (*continued*) — Untwinned grains (flat etch) × 100

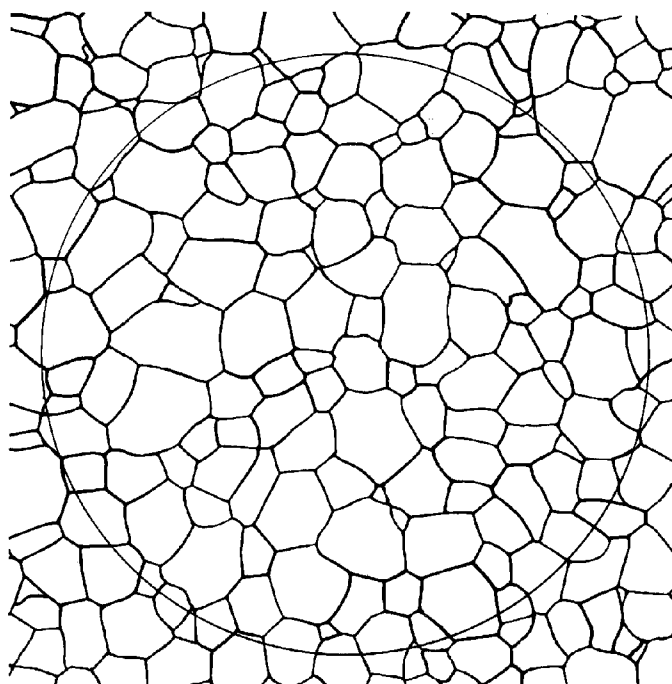


4.0

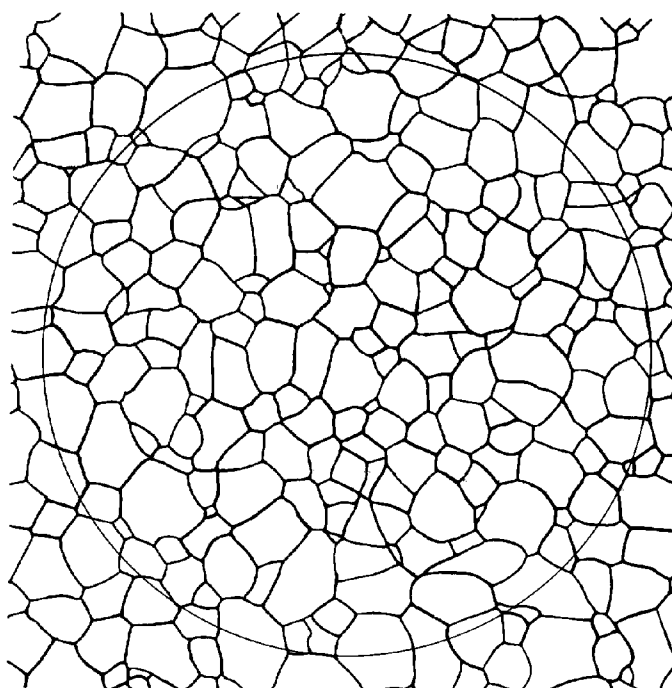


4.5

Plate 1B (*continued*) — Untwinned grains (flat etch) × 100

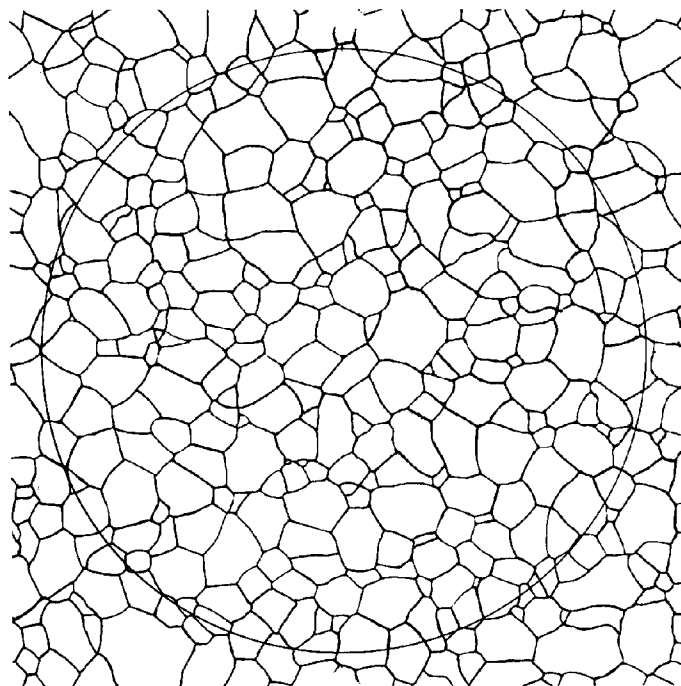


5.0

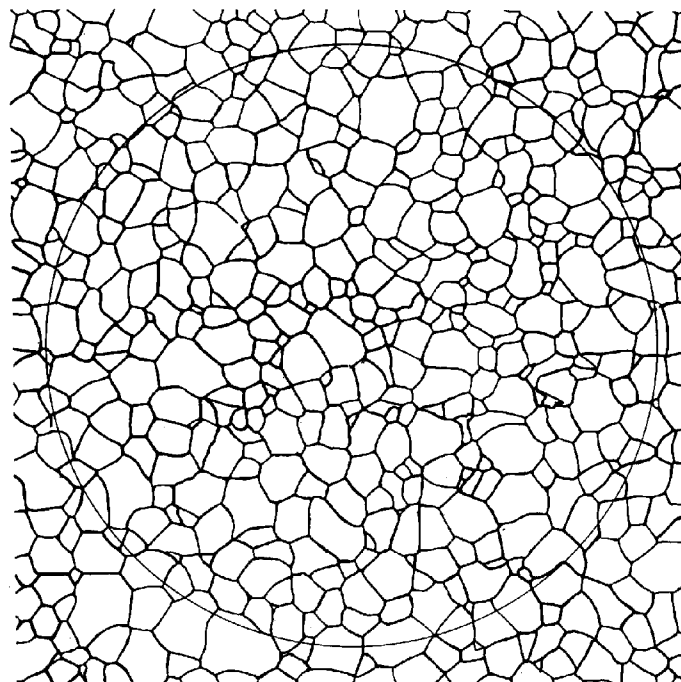


5.5

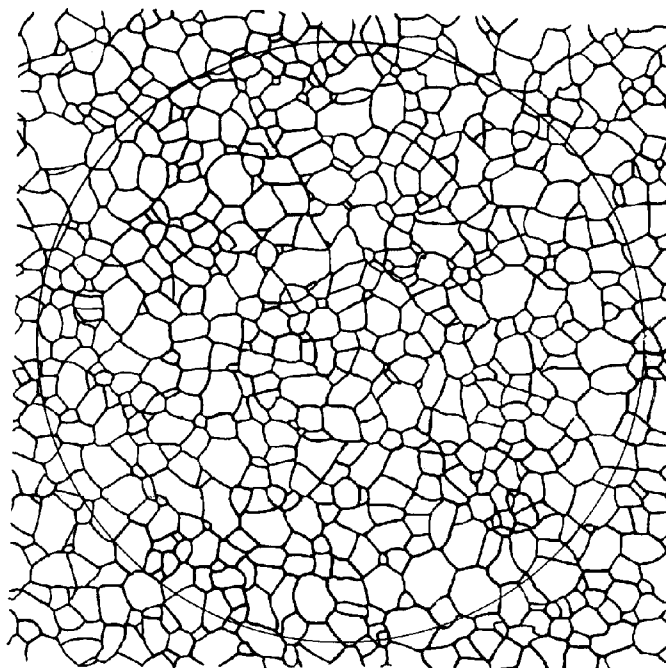
Plate 1B (*continued*) — Untwinned grains (flat etch) × 100



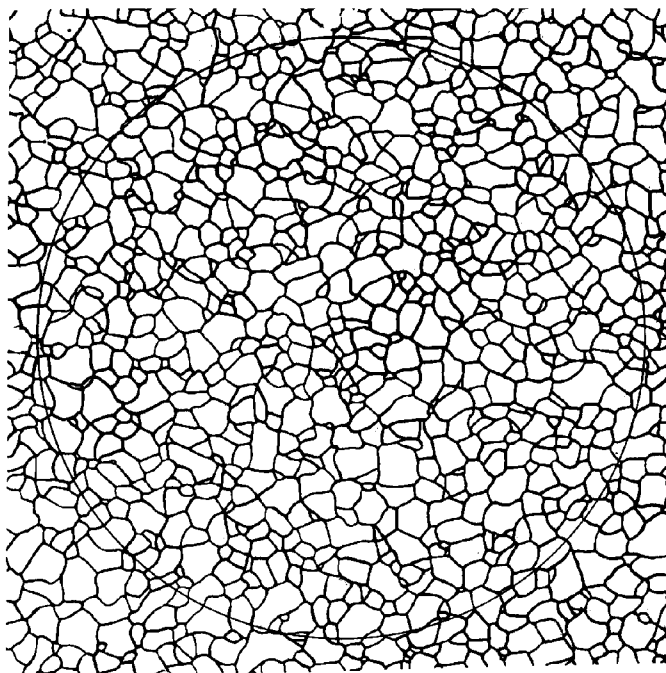
6.0



6.5

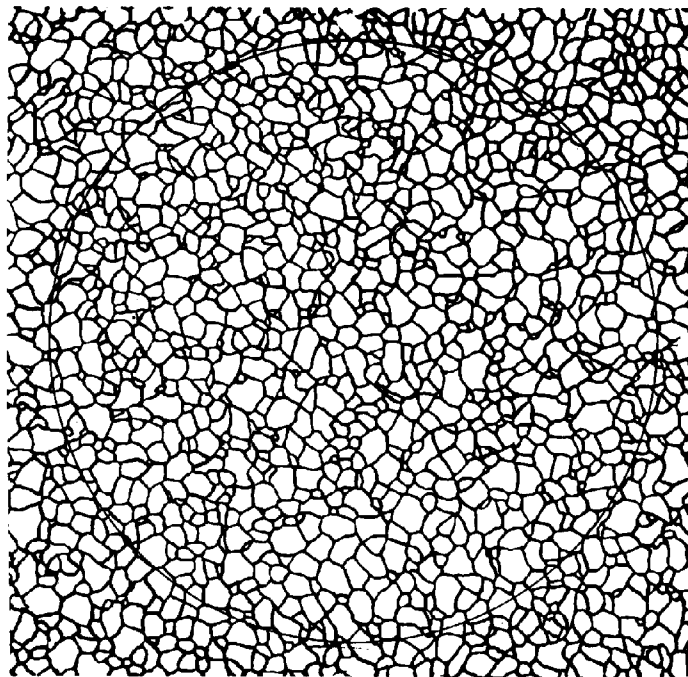
Plate 1B (*continued*) — Untwinned grains (flat etch) $\times 100$ 

7.0

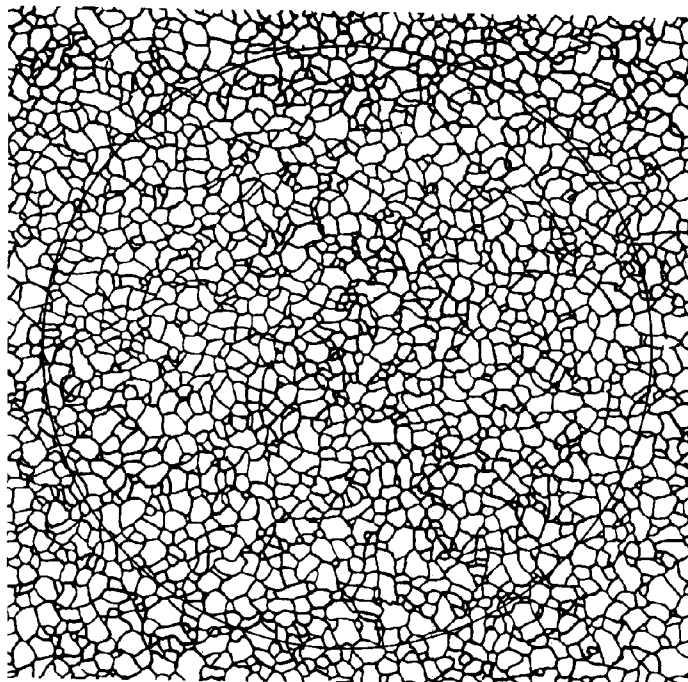


7.5

Plate 1B (*continued*) — Untwinned grains (flat etch) × 100

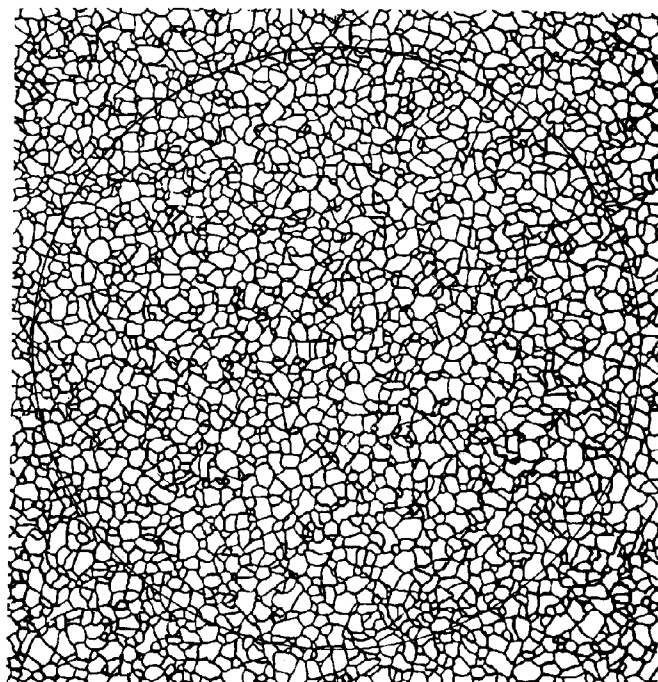


8.0

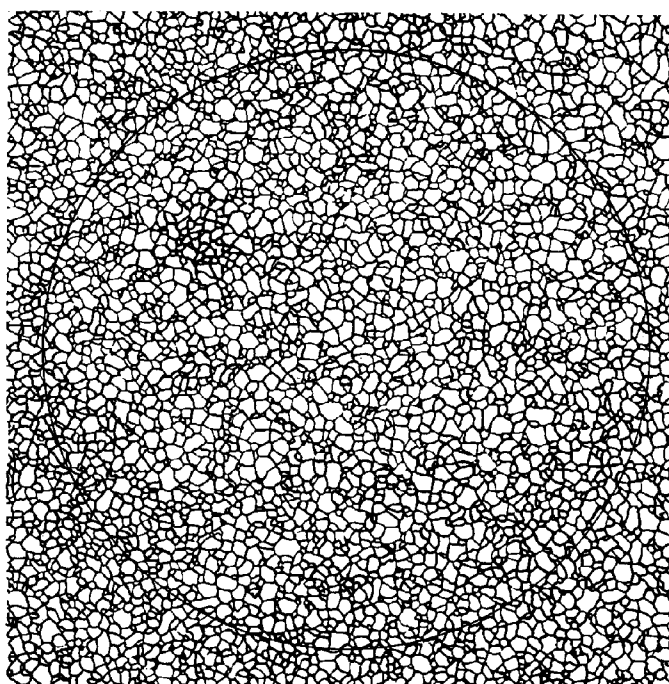


8.5

Plate 1B (*continued*) — Untwinned grains (flat etch) × 100

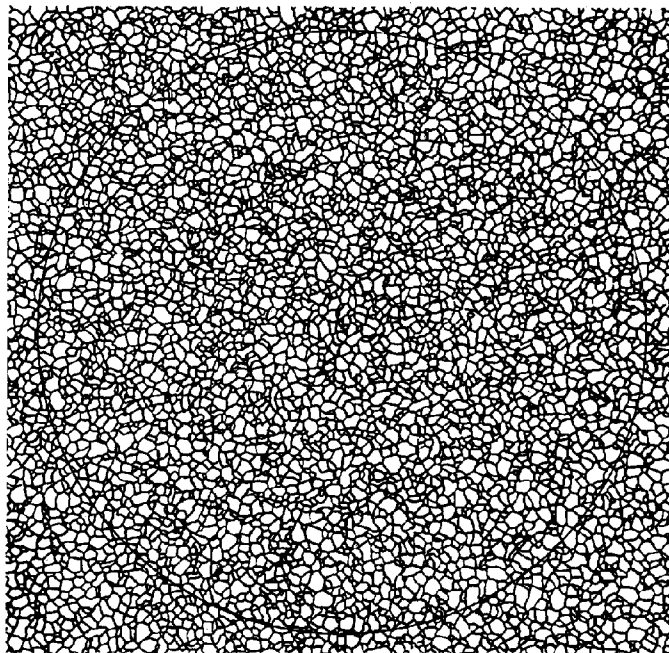


9.0



9.5

Plate 1B (*continued*) — Untwinned grains (flat etch) $\times 100$



10.0

Annex C (normative)

Evaluation method

C.1 Principle of the planimetric method

Historically, a circle measuring 79,8 mm in diameter was drawn on or superimposed over a micrograph or a live image on a ground glass projection screen. The magnification was adjusted so that the circular area contained at least 50 grains. This recommendation was made to minimize the counting error associated with a circular test pattern.

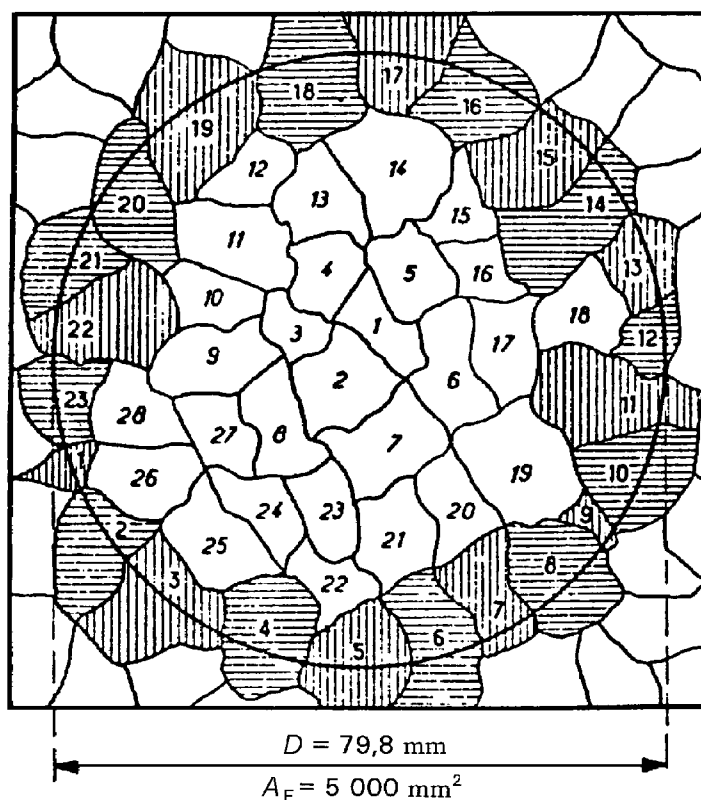


Figure C.1 — Evaluation of number of grains in an area enclosed by a circle

Two counts are made: n_1 is the number of grains completely within the test circle while n_2 is the number of grains intersected by the test circle.

The total number of equivalent grains is

$$n_{100} = n_1 + \frac{n_2}{2} \quad (\text{C.1})$$

The number of grains per mm^2 , m , on the specimen surface is computed from

$$m = 2n_{100} \quad (\text{C.2})$$

or, in the case of any magnification, g

$$m = (g^2/5\,000)n_g \quad (\text{C.3})$$

where 5 000 is the test circle area in mm^2 .

This approach assumes that, on average, half of the grains intersected by 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 for a curved line. The bias created by this assumption increases 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 is about 2 %.

A simple way to avoid this bias, irrespective of the number of grains within the test figure, is to use a square or rectangle. 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 figure and three-fourths outside. These four corner grains together equal one grain within the test box.

Ignoring the four corner grains, a count is made of n_1 , the grains completely within the box; and, n_2 , the grains intersected by the four sides of the box (see Figure C.1). Equation C.1 now becomes:

$$n_{100} = (n_1 + 0,5n_2 + 1) \quad (\text{C.4})$$

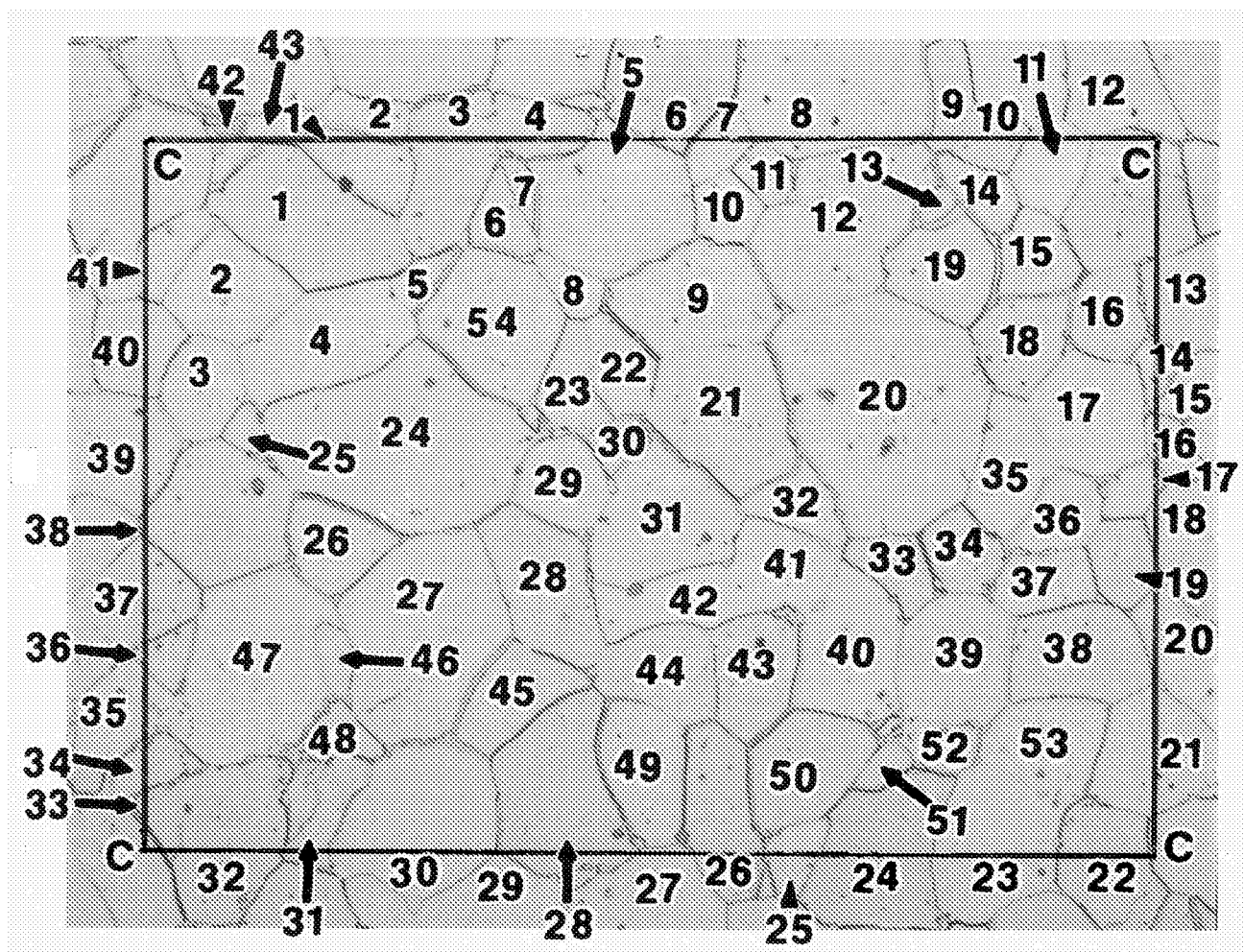


Figure C.2 — Evaluation of the number of intercepts or intersections

The number of grains per square millimetre, m , on the surface of the specimen is

$$m = (g^2/A_F) n_{100} \quad (\text{C.5})$$

where A_F is the apparent area of the test figure used for grain counting in mm^2 .

The mean grain area in square millimetres is calculated from

$$\bar{a} = \frac{1}{m} \quad (\text{C.6})$$

It has been common practice to calculate a mean grain diameter from the following equation, but use of this approach is not recommended as it implies that grains are square in cross section, which they are not.

$$\bar{d} = \bar{a}^{1/2} \quad (\text{C.7})$$

A nominal value of m corresponds to each value of G . The values of m calculated by formula (C.2) or (C.3) within the limits given in Table C.1 are given to a whole value of G .

C.2 “Snyder-Graff” method⁵⁾

C.2.1 Field of application

This method is used for determining the prior-austenitic grain size of hardened and tempered high-speed steels by means of the linear intercept method.

C.2.2 Preparation

The specimen, taken from the product that is usually in the hardened and tempered condition, shall not receive any supplementary heat treatment.

After being polished, the specimen shall be etched using nital containing up to 10 % by volume of nitric acid in ethanol. Etch the specimen long enough to clearly reveal the prior-austenitic grain boundaries. Several successive polish/etch cycles may be necessary. The surface of the specimen is more or less coloured depending on the type of heat treatment undergone by the product.

C.2.3 Measuring

Under a magnification of $\times 1\,000$, the number of grains intercepted by a measuring line 125 mm long shall be counted. Five counts shall be carried out in different directions in fields selected at random.

C.2.4 Result

Unless specified to the contrary, the arithmetic mean of the number of grains intercepted in five counts characterizes the grain size. The mean intercepted segment may be determined from this value.

5) Snyder, R.W. and Graff, H.F., Study of grain size in hardened high-speed steel, *Metal Progress* (1938), April, pp 377-80.

Table C.1 — Evaluation of number of grains as a function of various parameters

Grain size indices G	Number of grains, per square millimetre m			Mean diameter of grain $\bar{d}$ mm	Mean area of grain $\bar{a}$ mm ²	Mean intersected segment l mm	Mean number of intercepts on the measuring line, per millimetre
	Nominal value	Limit values					
		from (excl.)	to (incl.)				
−7	0,062 5	0,046	0,092	4	16	3,577	0,279
−6	0,125	0,092	0,185	2,828	8	2,529	0,395
−5	0,25	0,185	0,37	2	4	1,788	0,559
−4	0,50	0,37	0,75	1,414	2	1,265	0,790
−3	1	0,75	1,5	1	1	0,894	1,118
−2	2	1,5	3	0,707	0,5	0,632	1,582
−1 (00)	4	3	6	0,500	0,25	0,447	2,237
0	8	6	12	0,354	0,125	0,320	3,125
1	16	12	24	0,250	0,062 5	0,226	4,42
2	32	24	48	0,177	0,031 2	0,160	6,25
3	64	48	96	0,125	0,015 6	0,113	8,84
4	128	96	192	0,088 4	0,007 81	0,080	12,5
5	256	192	384	0,062 5	0,003 90	0,056 6	17,7
6	512	384	768	0,044 2	0,001 95	0,040 0	25,0
7	1 024	768	1 536	0,031 2	0,000 98	0,028 3	35,4
8	2 048	1 536	3 072	0,022 1	0,000 49	0,020 0	50,0
9	4 096	3 072	6 144	0,015 6	0,000 244	0,014 1	70,7
10	8 192	6 144	12 288	0,011 0	0,000 122	0,010 0	100
11	16 384	12 288	24 576	0,007 8	0,000 061	0,007 07	141
12	32 768	24 576	49 152	0,005 5	0,000 030	0,005 00	200
13	65 536	49 152	98 304	0,003 9	0,000 015	0,003 54	283
14	131 072	98 304	196 608	0,002 8	0,000 007 5	0,002 50	400
15	262 144	196 608	393 216	0,002 0	0,000 003 7	0,001 70	588
16	524 288	393 216	786 432	0,001 4	0,000 001 9	0,001 20	833
17	1 048 576	786 432	1 572 864	0,001 0	0,000 000 95	0,000 87	1 149
NOTE This table gives the values between the different parameters for equiaxed grains.							

C.3 An alternative system of grain size definition

C.3.1 General

In addition to the grain size definition system described in this International Standard, there is one other system, as used in the U.S.A.

This system (see ASTM E112) defines the grain size by an index G , known as the ASTM grain size, as shown in C.3.2 and C.3.3.

C.3.2 Mean intersected segment method

Index G (ASTM) = 0, corresponds to a mean intersected segment of 32,0 mm measured at a magnification of $\times 100$.

The equation giving the other indices as a function of

- the mean intersected segment is

$$G \text{ (ASTM)} = -3,287\,7 - 6,643\,9 \log l \quad (\text{C.8})$$

- the mean number of intercepts per unit length (mm) is

$$G \text{ (ASTM)} = -3,287\,7 + 6,643\,9 \log \bar{N}_L \quad (\text{C.9})$$

C.3.3 Count method

By definition, index G (ASTM) = 1 corresponds to 15,5 grains per unit area (square millimetre).

The equation giving the other indices as a function of the number of grain per unit area (square millimetre) is

$$G \text{ (ASTM)} = -2,954\,2 + 3,321\,9 \log m \quad (\text{C.10})$$

C.3.4 Numerical ratios between the various grain size indices in the case of regular structures

The ASTM index gives a grain size slightly larger than the one defined by this International Standard, but the difference does not reach one twentieth of an index unit. This is negligible, as the estimation of grain size cannot generally be accurate to more than one half a unit under even the most favourable conditions.

Equations (2a) and (2b) given in 7.1 may be written as

$$G = -3 + 3,321\,9 \log m \quad (\text{C.11})$$

Comparing this formula with formula (C.10) shows that

$$G \text{ (ASTM)} - G = 0,045\,8$$

BSI — British Standards Institution

BSI is the independent national body responsible for preparing British Standards. It presents the UK view on standards in Europe and at the international level. It is incorporated by Royal Charter.

Revisions

British Standards are updated by amendment or revision. Users of British Standards should make sure that they possess the latest amendments or editions.

It is the constant aim of BSI to improve the quality of our products and services. We would be grateful if anyone finding an inaccuracy or ambiguity while using this British Standard would inform the Secretary of the technical committee responsible, the identity of which can be found on the inside front cover. Tel: +44 (0)20 8996 9000. Fax: +44 (0)20 8996 7400.

BSI offers members an individual updating service called PLUS which ensures that subscribers automatically receive the latest editions of standards.

Buying standards

Orders for all BSI, international and foreign standards publications should be addressed to Customer Services. Tel: +44 (0)20 8996 9001. Fax: +44 (0)20 8996 7001. Email: orders@bsi-global.com. Standards are also available from the BSI website at <http://www.bsi-global.com>.

In response to orders for international standards, it is BSI policy to supply the BSI implementation of those that have been published as British Standards, unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and international standards through its Library and its Technical Help to Exporters Service. Various BSI electronic information services are also available which give details on all its products and services. Contact the Information Centre. Tel: +44 (0)20 8996 7111. Fax: +44 (0)20 8996 7048. Email: info@bsi-global.com.

Subscribing members of BSI are kept up to date with standards developments and receive substantial discounts on the purchase price of standards. For details of these and other benefits contact Membership Administration. Tel: +44 (0)20 8996 7002. Fax: +44 (0)20 8996 7001. Email: membership@bsi-global.com.

Information regarding online access to British Standards via British Standards Online can be found at <http://www.bsi-global.com/bsonline>.

Further information about BSI is available on the BSI website at <http://www.bsi-global.com>.

Copyright

Copyright subsists in all BSI publications. BSI also holds the copyright, in the UK, of the publications of the international standardization bodies. Except as permitted under the Copyright, Designs and Patents Act 1988 no extract may be reproduced, stored in a retrieval system or transmitted in any form or by any means – electronic, photocopying, recording or otherwise – without prior written permission from BSI.

This does not preclude the free use, in the course of implementing the standard, of necessary details such as symbols, and size, type or grade designations. If these details are to be used for any other purpose than implementation then the prior written permission of BSI must be obtained.

Details and advice can be obtained from the Copyright & Licensing Manager. Tel: +44 (0)20 8996 7070. Fax: +44 (0)20 8996 7553. Email: copyright@bsi-global.com.

BSI
389 Chiswick High Road
London
W4 4AL