
Method for
The estimation of
equivalent diameters in
the heat treatment
of steel

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British Constructional Steelwork Association
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British Ironfounders' Association
British Mechanical Engineering Confederation
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Foreword

This British Standard method has been prepared under the authority of the Iron and Steel Industry Standards Committee. It was originally prepared to supplement BS 4670 'Alloy steel forgings' but the concepts of equivalent diameter and ruling section are so widely used in heat-treatment technology that the scope was broadened to include all cases where it is practicable to apply the concept.

This standard enables the equivalent diameter to be estimated for most objects encountered in steel heat-treatment. However, most steel standards quote minimum properties for given limiting ruling sections and a full explanation is given in this standard to facilitate its practical application. It is therefore hoped that other committees responsible for standards using the equivalent diameter/ruling section concept will now feel able to specify this standard, thus obviating the need, within those standards, to include detailed explanations and guidance on the subject.

British Standard Method for The estimation of equivalent diameters in the heat treatment of steel

1. Scope

1.1 This British Standard provides data for the estimation of the equivalent diameters of pieces of steel of relatively simple shape (hereafter referred to as 'objects').

The information is not confined to one type of product, e.g. forgings as distinct from castings or rolled plate, but refers to all objects undergoing a cooling process from an elevated temperature down to ambient temperature by being allowed to stand in still air or by immersion in oil or water.

1.2 The main application of this standard is to the hardening of steels, i.e. to those heat-treatments intended to develop certain desired mechanical properties. It may also be applied to other heat-treatment operations involving similar cooling conditions, where the concept of 'equivalent diameter' (as defined in 2.2) is still relevant.

1.3 This standard applies to the following shapes:

- (1) cylinders and discs;
- (2) rectangular sections, including plates;
- (3) rings and tubes;
- (4) certain axially symmetric shapes with varying cross sections.

1.4 Guidance for the estimation of equivalent diameters for some other miscellaneous shapes is given in Appendix C. Details of the basis used for the calculation have been included in Appendix A.

NOTE. The title of the British Standard referred to in this standard is given on the inside back cover.

2. Terminology

2.1 **Introduction.** For a hardenable steel of given composition, the mechanical properties are dependent on the rate of cooling from a hardening temperature. For a given cooling medium (air, oil or water) the cooling rate is determined by the size and shape of the object, larger bulkier objects cooling slower than smaller lighter ones. The cooling rate will also vary with position inside the object, points in the interior cooling slower than points near the surface.

For the purposes of this standard, objects of different shape or size are compared in terms of the cooling rates at their slowest-cooling positions.

2.2 **Equivalent diameter.** The *equivalent diameter* of any object (or part of an object), is the diameter at the time of heat-treatment of a hypothetical very long bar (effectively of infinite length) of uniform circular cross section which, if subjected to the same cooling conditions as the object (i.e. the same initial and final temperatures, and same cooling medium), would have a cooling rate at its axis equivalent to that at the slowest-cooling position in the object or relevant part.

For an actual long round bar, the equivalent diameter is thus the same as the actual diameter. For other shapes, or shorter round bars, the equivalent diameter may be obtained by calculation using Tables 1 to 12 of this standard.

It should be noted, however, that for different shapes there are different ways of defining 'equivalent cooling rates'. The particular definition chosen for the purposes of this standard, and other relevant details of the calculations, are described in Appendix A.

When comparing the tables for different cooling media, it is essential to bear in mind that the difference in equivalent diameters for a given object in no way reflects the actual cooling rates in the different media. Thus, an object and its equivalent bar (i.e. of diameter equal to the equivalent diameter of the object) may cool at nominally the same rate in, say, air. If they were both water quenched they would both cool very much faster than for the air cooling condition, but the new cooling rate of the bar would still be not greatly different from that of the object. The much greater cooling rate of the water quenched condition is thus not reflected in a large change of equivalent diameter.

Certain objects consist of more than one bulky portion joined by a thinner portion, such as a forged shaft with two or three enlarged collars or flanges. The bulkier parts will generally cool slower than the remainder, and each will thus have an appropriate equivalent diameter.

2.3 Ruling section. This is the equivalent diameter of that portion of the object at the time of heat treatment that is most important in relation to mechanical properties.

In some instances, the purchaser may not be interested in the mechanical properties at the slowest-cooling position, but rather at some faster-cooling position. For example, a valve spindle forging consists of a large diameter head with a long slender stem where the properties of the head may not be very critical, as it may receive further treatment, e.g. hard facing, so that the stem becomes the most important portion as regards mechanical properties. The ruling section is then the diameter of the stem, and not the equivalent diameter of the head and stem together.

2.4 Limiting ruling section. For any given composition of steel, the 'limiting ruling section' is the largest diameter in which certain specified mechanical properties can be expected after a specified heat-treatment.

NOTE. Selection of material. When a steel is to be selected for the manufacture of a particular object, either the user will require certain mechanical properties dictated by the design, or the choice of steel may be dictated by other considerations (price, availability, machineability, etc.) and the user will require to know the mechanical properties that can be obtained. In either case, the ruling section of the object at the time of heat-treatment should be estimated from Tables 1 to 12, unless a situation such as described in 2.3 arises. Reference to material specifications will then generally allow a suitable steel to be selected, information on available properties to be provided.

3. Tables of equivalent diameters

3.1 General. Equivalent diameters shall be estimated as described below using the data given in Tables 1 to 12.

3.2 Cylinders and discs. In the following Tables 1 to 3, the equivalent diameter in millimetres shall be read directly from the dimensions in millimetres of the object. The values of dimensions for which the equivalent diameters are tabulated are the 'preferred' numbers given in BS 2045. For intermediate values, approximate linear interpolation is adequate.

Table 1. Equivalent diameters for cylinders and discs, air cooled

Diameter (mm)	Length or thickness (mm)													
	10	12	16	20	25	30	40	50	60	80	100	120	160	∞
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
10	6.7	7.1	7.6	8.1	8.4	8.7	9.0	9.2	9.4	9.5	9.6	9.7	9.7	10
12	7.6	8.0	8.8	9.4	9.8	10	11	11	11	11	11	12	12	12
16	9.0	9.6	11	11	12	13	13	14	14	15	15	15	15	16
20	10	11	12	13	14	15	16	17	17	18	18	19	19	20
25	11	12	14	16	17	18	19	20	21	22	23	23	23	25
30	12	14	16	17	19	20	22	24	25	26	27	28	28	30
40	14	15	18	20	22	25	27	28	31	33	35	36	37	40
50	15	17	20	23	25	28	32	34	36	39	41	43	45	50
60	15	18	21	25	28	31	36	39	41	44	48	50	53	60
80	16	19	23	27	31	35	41	46	50	55	59	62	67	80
100	17	20	25	29	35	39	46	52	57	66	69	73	80	100
120	18	21	26	31	37	42	50	57	62	73	80	84	92	120
160	18	21	27	33	39	45	56	65	73	86	95	105	115	160
200	18	22	28	34	41	48	60	71	80	96	105	120	135	200
250	19	22	29	35	43	50	64	76	87	105	120	135	155	250
300	19	22	29	36	44	52	66	80	92	115	130	145	170	300
400	19	23	30	37	45	53	69	85	98	125	145	165	200	400
500	19	23	30	37	46	55	70	88	105	130	160	180	220	500
600	19	23	30	38	47	55	73	90	105	135	165	190	240	600
800	19	23	31	38	48	57	74	93	110	140	175	205	265	800
1000	20	23	31	38	48	57	76	95	110	145	180	210	275	1000
1200	20	24	31	38	48	57	76	95	115	150	185	215	285	1200
1600	20	24	31	39	48	57	77	96	115	150	185	220	285	1600
2000	20	24	31	39	49	57	77	96	115	150	190	220	290	2000
∞	20	24	32	39	49	58	78	96	115	150	190	225	290	—

Table 1. (continued)

Diameter (mm)	Length or thickness (mm)													
	160	200	250	300	400	500	600	800	1000	1200	1600	2000	2500	∞
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
30	28	28	29	29	29	29	30	30	30	30	30	30	30	30
40	37	38	38	39	39	39	39	40	40	40	40	40	40	40
50	45	46	47	48	48	49	49	49	50	50	50	50	50	50
60	53	55	56	57	58	59	59	59	59	60	60	60	60	60
80	67	70	73	75	77	77	78	79	79	80	80	80	80	80
100	80	85	89	91	95	97	98	99	99	100	100	100	100	100
120	92	98	105	110	110	115	115	120	120	120	120	120	120	120
160	115	125	130	140	145	150	155	155	160	160	160	160	160	160
200	135	145	155	165	175	185	190	195	195	200	200	200	200	200
250	155	170	185	195	210	225	230	240	245	245	250	250	250	250
300	170	190	210	235	245	260	270	285	290	295	300	300	300	300
400	200	225	250	275	300	330	350	370	380	390	390	400	400	400
500	220	250	280	310	360	380	410	440	460	480	490	500	500	500
600	240	275	320	350	400	440	470	520	550	560	580	590	600	600
800	265	310	360	400	480	530	580	650	700	730	760	780	790	800
1000	275	330	390	440	540	600	670	760	830	870	930	960	990	1000
1200	285	350	410	470	580	660	740	860	940	1010	1090	1150	1170	1200
1600	285	355	440	510	630	750	840	1000	1120	1260	1370	1440	1510	1600
2000	290	360	440	520	660	800	910	1110	1270	1420	1620	1740	1830	2000
2500	290	360	440	520	680	830	950	1190	1400	1560	1830	2050	2170	2500
3000	290	360	440	520	680	830	980	1250	1480	1650	2000	2260	2500	3000
4000	290	360	440	520	680	840	990	1290	1560	1760	2220	2560	2920	4000
∞	290	360	440	520	680	840	990	1300	1600	1800	2400	2940	3680	—

Table 2. Equivalent diameters for cylinders and discs, oil quenched

Diameter (mm)	Length or thickness (mm)													
	10	12	16	20	25	30	40	50	60	80	100	120	160	∞
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
10	7.4	7.9	8.6	9.1	9.4	9.6	9.8	9.9	9.9	10	10	10	10	10
12	8.5	9.0	10	11	11	11	12	12	12	12	12	12	12	12
16	10	11	12	13	14	15	15	16	16	16	16	16	16	16
20	11	13	14	16	17	18	19	19	20	20	20	20	20	20
25	13	14	17	18	20	21	23	23	24	25	25	25	25	25
30	14	16	19	21	23	24	26	28	29	29	30	30	30	30
40	16	18	21	24	27	30	33	35	37	39	39	40	40	40
50	16	19	23	27	31	34	39	42	45	47	48	49	50	50
60	17	20	25	29	34	37	43	48	50	55	57	58	60	60
80	17	20	26	32	37	42	50	57	62	69	73	77	78	80
100	18	21	27	33	39	45	55	63	70	80	87	92	97	100
120	18	21	27	33	40	47	58	68	76	91	98	105	115	120
160	18	21	27	33	41	48	61	73	84	100	115	125	140	160
200	18	21	27	33	41	48	63	76	89	110	130	145	165	200
250	18	21	27	33	41	48	63	78	91	115	140	155	185	250
300	18	21	27	33	41	48	63	78	92	120	145	165	200	300
400	18	21	27	33	41	48	63	78	92	120	150	175	220	400
500	18	21	27	33	41	48	63	78	92	120	150	175	230	500
600	18	21	27	33	41	48	63	78	92	120	150	175	230	600
800	18	21	27	33	41	48	63	78	92	120	150	180	235	800
∞	18	21	27	33	41	48	63	78	92	120	150	180	235	—

Table 2. (continued)

Diameter (mm)	Length or thickness (mm)													
	160	200	250	300	400	500	600	800	1000	1200	1600	2000	2500	∞
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
80	78	80	80	80	80	80	80	80	80	80	80	80	80	80
100	97	99	100	100	100	100	100	100	100	100	100	100	100	100
120	115	120	120	120	120	120	120	120	120	120	120	120	120	120
160	140	150	155	155	160	160	160	160	160	160	160	160	160	160
200	165	175	185	195	200	200	200	200	200	200	200	200	200	200
250	185	205	220	230	245	250	250	250	250	250	250	250	250	250
300	200	230	250	265	285	290	295	300	300	300	300	300	300	300
400	220	255	295	320	360	370	390	400	400	400	400	400	400	400
500	230	280	320	360	410	440	460	490	500	500	500	500	500	500
600	230	290	340	390	460	500	540	570	590	600	600	600	600	600
800	235	290	360	420	510	590	640	720	750	780	800	800	800	800
1000	235	295	360	430	550	640	720	830	900	940	980	1000	1000	1000
1200	235	295	360	430	570	680	770	910	1010	1070	1160	1180	1200	1200
1600	235	295	360	440	580	720	840	1030	1180	1290	1430	1510	1570	1600
2000	235	295	360	440	580	720	850	1100	1290	1450	1660	1800	1890	2000
2500	235	295	360	440	580	720	860	1130	1380	1560	1870	2080	2250	2500
3000	235	295	360	440	580	720	860	1130	1410	1630	2020	2300	2570	3000
∞	235	295	360	440	580	720	860	1130	1410	1700	2260	2830	3540	—

Table 3. Equivalent diameters for cylinders and discs, water quenched

(For all other larger sizes water quenched, assume the values for oil quenching)

Diameter (mm)	Length or thickness (mm)											
	10	12	16	20	25	30	40	50	60	80	100	∞
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
10	7.9	8.4	9.0	9.4	9.7	9.9	10	10	10	10	10	10
12	8.9	9.6	11	11	11	12	12	12	12	12	12	12
16	11	12	14	14	15	15	15	15	15	16	16	16
20	12	14	16	17	18	19	19	19	20	20	20	20
25	14	15	18	20	22	22	23	23	24	24	25	25
30	15	16	20	22	25	26	27	28	29	29	30	30
40	16	18	22	25	29	32	35	36	37	38	39	40
50	16	19	23	27	32	36	40	43	45	47	48	50
60	16	19	24	29	34	39	45	49	52	54	56	60
80	16	19	25	31	36	42	51	59	64	68	73	80
100	16	19	25	31	37	44	55	64	71	79	89	100
120	16	19	25	31	38	45	57	66	76	88	99	120
160	16	19	25	31	38	46	59	69	79	98	110	160
200	16	19	25	31	38	46	60	71	85	105	120	200
250	16	19	25	31	38	46	60	72	85	110	130	250
300	16	19	25	31	38	46	60	73	86	115	135	300
400	16	19	25	31	38	46	60	74	87	115	140	400
500	16	19	25	31	38	46	60	74	88	115	145	500
∞	16	19	25	31	38	46	60	74	88	115	145	