Chapter 1-1

METHODS OF TESTING (METALLOGRAPHY)

CONTENTS

GENERAL INFORMATION

1 Methods and appliances for testing of metals and alloys have been devised in order to determine the relative degree to which various characteristics are possessed by a metal.

2 The relevant specification (Chap.1-0, para. 7) must be referred to when full particulars regarding the composition and treatment of metals and alloys are required.

3 Metals and alloys are developed and heat-treated in order to obtain or improve the properties required in the finished article for the particular purposes for which it is to be used. In order to ensure that the properties are obtained correctly to the degree required, and to ascertain whether undesirable properties have been eliminated or not, it is essential that tests are made during the course of production. In many instances, tests are necessary up to the final stage when the metal is put into use, especially so in the case of metals to be used in the construction and

repair of aircraft, aircraft components and other service equipment. Several such tests are detailed in the specifications referred to in Chap. 1-0, para. 7. Para. 10 to 23 of this Chapter give a brief survey of these tests.

CHEMICAL ANALYSIS

4 Samples of metals are taken from the ingots or from the moulds, care being taken to ensure that the test pieces are representative of the whole.

5 The relevant B.S. must be consulted with regard to the sampling scale. This may vary, dependent on the size and weight of each cast, from proportional to total batch sampling.

6 Test pieces may be taken after this stage by drilling out samples for test.

7 The metal cuttings obtained, are then subjected to various applications of heat and chemicals (by skilled metallurgists), to determine the presence and percentage composition of the constituents. Separate processes are employed according to the nature of the element (and the presence of other elements) in the alloy under test.

8 A further chemical process employed is chemical etching (sulphur printing), and may be used to show:

8.1 The depth of case hardening.

8.2 The direction of grain.

8.3 Grain size.

8.4 The nature of welds.

9 In this process, a specimen test piece, with a highly polished surface, is subjected to the effect of various etching solutions, e.g. nitric, picric or other acids. The specimen is then photographed (with magnifications up to 5,000 diameters) the results being analysed by an approved metallurgist. An analysis of each ingot (mould) cast is to be supplied to prove that the ingot is free of harmful inclusions.

TENSILE TESTING

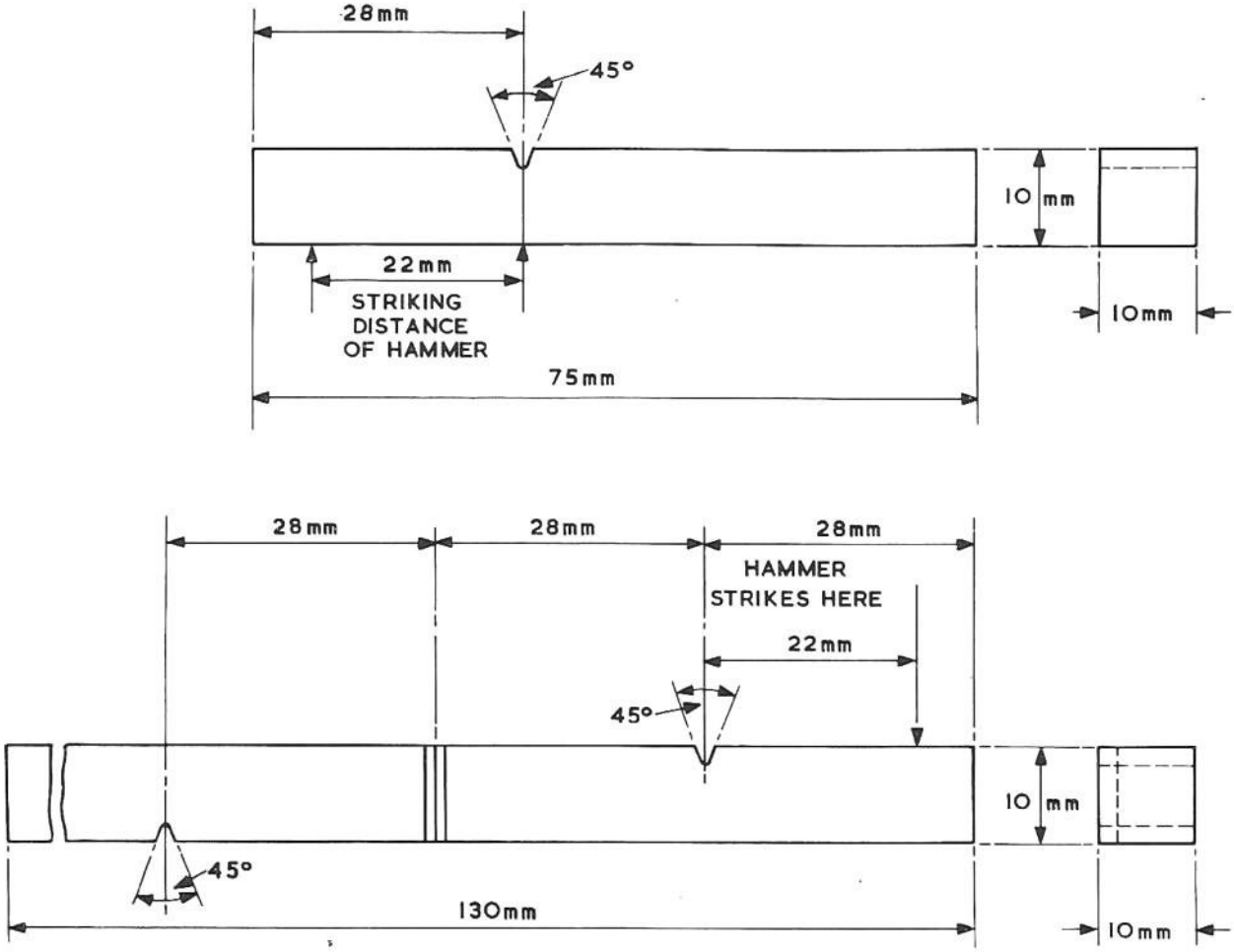
10 This is normally carried out at room temperature, generally in accordance with the provisions of BS.4A4, BS.1610 and BS.3846.

11 Controlled tests on standard test pieces (fig. 1) (of a specified length and cross-sectional area) of the material being tested are carried out to determine:

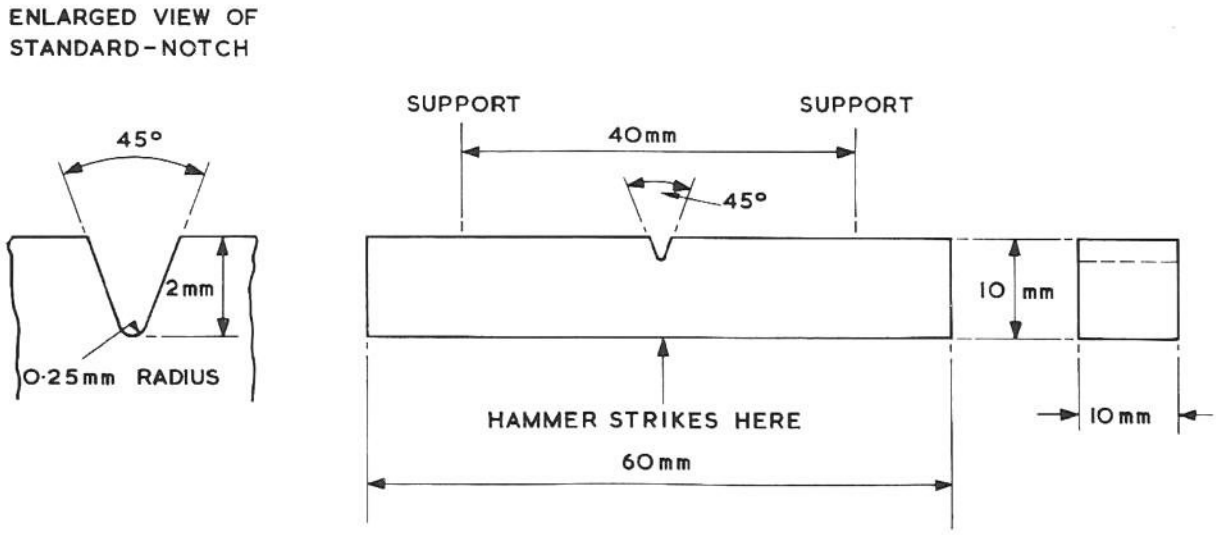
11.1 Elasticity (stretching) - using Young's modulus, defined as the ratio:

$$E = \frac{\text{tensile (or compressive) stress}}{\text{tensile (or compressive) strain}}$$

where stress is defined as a load on a test piece divided by the original cross-sectional area of the parallel portion, and strain is defined as the extension per unit length.



CANTILEVER TYPE TEST PIECES



BEAM TYPE TEST PIECE

Fig. 1 Standard notched bar dimensions

TABLE 1 HARDNESS NUMBERS OBTAINED BY DIFFERENT TESTS

Brinell	Vickers	Rockwell		Scleroscope	Brinell	Vickers	Rockwell		Scleroscope
10 mm Ball 3000 Kg.	120 Kg.	C 120° Cone 150 Kg.	B 1/16 in Ball 100 Kg	Shore Model C	10 mm Ball 3000 Kg.	120 Kg.	C 120° Cone 150 Kg.	B 1/16 in Ball 100 Kg.	Shore Model C
800	..	72	..	100	502	565	52	119	70
780	1220	71	..	99	495	551	51	119	69
760	1170	70	..	98	477	534	49	118	67
745	1114	68	..	97	461	502	48	117	66
725	1060	67	..	96	451	489	47	117	65
712	1021	66	..	95	444	474	46	116	64
682	940	65	..	93	427	460	45	115	62
668	905	64	..	91	415	435	44	115	60
652	867	63	..	89	401	423	43	114	58
626	803	62	..	87	388	401	42	114	57
614	775	61	..	85	375	390	41	113	55
601	746	60	..	83	370	385	40	112	54
590	727	59	..	81	362	380	39	111	53
576	694	57	..	79	351	361	38	111	51
552	649	56	..	76	346	352	37	110	50
545	639	55	..	75	341	344	37	110	49
529	606	54	..	74	331	335	36	109	47
514	587	53	130	72	323	320	35	109	46

These conversion or equivalent hardness numbers are approximate only, because of variations in methods of testing hardness with different types of equipment.

(continued)

TABLE 1 HARDNESS NUMBERS OBTAINED BY DIFFERENT TESTS (continued)

Brinell	Vickers	Rockwell		Scleroscope	Brinell	Vickers	Rockwell		Scleroscope
10 mm Ball 3000 Kg.	120 Kg.	C 120° Cone 150 Kg.	B 1/16 in Ball 100 Kg.	Shore Model C	10 mm Ball 3000 Kg.	120 Kg.	C 120° Cone 150 Kg.	B 1/16 in Ball 100 Kg.	Shore Model C
311	312	34	108	46	203	201	17	94	31
301	305	33	107	45	200	199	16	93	31
293	291	32	106	44	196	197	15	92	30
285	285	31	105	43	191	190	14	92	30
276	278	30	105	42	187	186	13	91	29
269	272	29	104	41	185	184	12	91	29
261	261	28	103	40	183	183	11	90	28
258	258	27	102	39	180	177	10	89	28
255	255	26	102	39	175	174	9	88	27
249	250	25	101	38	170	171	7	87	27
245	246	24	100	37	167	168	6	87	27
240	240	23	99	36	165	165	5	86	26
237	235	23	99	35	163	162	4	85	26
229	226	22	98	34	160	159	3	84	25
224	221	21	97	33	156	154	2	83	25
217	217	20	96	33	154	152	1	82	25
211	213	19	95	32	152	150	..	82	24
206	209	18	94	32	150	149	..	81	24

These conversion or equivalent hardness numbers are approximate only, because of variations in methods of testing hardness with different types of equipment.

(continued)

TABLE 1 HARDNESS NUMBERS OBTAINED BY DIFFERENT TESTS (continued)

Brinell	Vickers	Rockwell		Scleroscope	Brinell	Vickers	Rockwell		Scleroscope
10 mm Ball 3000 Kg.	120 Kg.	C 120° Cone 150 Kg.	B 1/16 in Ball 100 Kg	Shore Model C	10 mm Ball 3000 Kg.	120 Kg.	C 120° Cone 150 Kg.	B 1/16 in Ball 100 Kg.	Shore Model C
147	147	..	80	24	140	141	..	77	22
145	146	..	79	23	135	135	..	75	22
143	144	..	79	23	130	130	..	72	22
141	142	..	78	23					

These conversion or equivalent hardness numbers are approximate only, because of variations in methods of testing hardness with different types of equipment.

TABLE 2 BRINELL AND EQUIVALENT ROCKWELL HARDNESS NUMBERS B, E, F AND G SCALES/ROCKWELL SUPERFICIAL

Brinell Numbers, 500 kg. Load	Rockwell B, E, F and G Scales				Rockwell Superficial		
	B Scale, 1/16 in Ball, 100 kg., Red Figures	E Scale, 1/8 in Ball, 100 kg., Red Figures	F Scale, 1/16 in Ball, 60 kg., Red Figures	G Scale, 1/16 in Ball 150 kg., Red Figures	15-T Scale, 1/16 in Ball, 15 kg., Load	30-T Scale, 1/16 in Ball, 30 kg., Load	45-T Scale, 1/16 in Ball, 45 kg., Load
242	100	114.5	114.0	82.0	93.0	83.0	73.0
235	99	114.0	113.5	80.0	92.5	82.5	72.0
228	98	113.5	112.5	78.5	92.5	82.0	71.0
222	97	113.0	112.0	77.0	92.0	81.0	70.0
216	96	112.5	111.5	75.5	92.0	80.5	69.0
210	95	112.0	111.0	74.0	91.5	80.0	68.0
205	94	111.5	110.5	72.0	91.0	79.0	67.0
200	93	111.0	110.0	70.0	91.0	78.5	66.0
195	92	110.5	109.5	68.5	90.5	78.0	65.0
190	91	110.0	109.0	67.0	90.0	77.0	64.0
185	90	109.5	108.5	65.5	90.0	76.5	63.0
179	89	109.0	108.0	64.0	89.5	76.0	62.0
176	88	108.5	107.5	62.0	89.5	75.0	61.0
172	87	108.0	107.0	60.0	89.0	74.5	60.0
169	86	107.5	106.0	58.5	89.0	74.0	59.5
165	85	107.0	105.5	57.0	88.5	73.5	58.5
162	84	106.5	105.0	55.0	88.0	73.0	57.5
159	83	106.0	104.5	53.5	88.0	72.0	56.5

(continued)

TABLE 2 BRINELL AND EQUIVALENT ROCKWELL HARDNESS NUMBERS B, E, F AND G SCALES/ROCKWELL SUPERFICIAL (continued)

Brinell Numbers, 500 kg. Load	Rockwell B, E, F and G Scales				Rockwell Superficial		
	B Scale, 1/16 in Ball, 100 kg., Red Figures	E Scale, 1/8 in Ball, 100 kg., Red Figures	F Scale, 1/16 in Ball, 60 kg., Red Figures	G Scale, 1/16 in Ball, 150 kg., Red Figures	15-T Scale 1/16 in Ball, 15 kg., Load	30-T Scale, 1/16 in Ball, 30 kg., Load	45-T Scale, 1/16 in Ball, 45 kg., Load
156	82	105.5	104.0	52.0	87.5	71.5	55.5
153	81	105.0	103.5	50.0	87.0	71.0	54.5
150	80	104.5	103.0	48.5	87.0	70.5	53.5
147	79	104.0	102.0	47.0	86.5	70.0	52.5
144	78	103.5	101.5	45.5	86.5	69.0	52.0
141	77	103.0	101.0	43.5	86.0	68.5	51.0
139	76	102.5	100.5	42.0	86.0	68.0	50.0
137	75	102.0	100.0	40.5	85.5	67.5	49.0
135	74	101.5	99.5	38.5	85.0	66.5	48.5
132	73	101.0	99.0	37.0	85.0	66.0	47.5
130	72	100.5	98.5	35.5	84.5	65.5	46.5
127	71	100.0	98.0	33.5	84.0	65.0	45.5
125	70	99.5	97.5	32.0	84.0	64.0	44.5
123	69	99.0	97.0	30.5	83.5	63.5	43.5
121	68	98.5	96.0	28.5	83.5	63.0	42.5
119	67	98.0	95.5	27.0	83.0	62.0	42.0
117	66	97.5	95.0	25.5	83.0	61.5	41.0
116	65	97.0	94.5	24.0	82.5	61.0	40.0

(continued)

TABLE 2 BRINELL AND EQUIVALENT ROCKWELL HARDNESS NUMBERS B, E, F and G SCALES/ROCKWELL SUPERFICIAL (continued)

Brinell Numbers, 500 kg. Load	Rockwell B, E, F and G Scales				Rockwell Superficial		
	B Scale, 1/16 in Ball, 100 kg., Red Figures	E Scale, 1/8 in Ball 100 kg., Red Figures	F Scale 1/16 in Ball, 60 kg., Red Figures	G Scale, 1/16 in Ball, 150 kg., Red Figures	15-T Scale 1/16 in Ball, 15 kg., Load	30-T Scale 1/16 in Ball, 30 kg., Load	45-T Scale 1/16 in Ball, 45 kg., Load
114	64	96.5	94.0	22.0	82.0	60.5	39.0
112	63	96.0	93.5	20.5	82.0	60.0	38.0
110	62	95.5	93.0	19.0	81.5	59.0	37.0
108	61	95.0	92.5	17.5	81.0	58.5	36.0
107	60	94.5	92.0	16.0	81.0	58.0	35.0
106	59	94.0	91.0	14.0	80.5	57.5	34.0
104	58	93.5	90.5	12.5	80.5	57.0	33.0
103	57	93.0	90.0	11.0	80.0	56.0	32.5
101	56	92.5	89.5	9.5	80.0	55.5	31.5
100	55	92.0	89.0	8.0	79.5	55.0	30.5
98	54	91.0	88.5	6.0	79.0	54.5	29.5
97	53	90.5	88.0	4.5	79.0	53.5	28.5
96	52	90.0	87.0	2.5	78.5	53.0	28.0
95	51	89.5	86.5	1.0	78.0	52.5	27.0
93	50	89.0	86.0	. . . .	78.0	52.0	26.0
92	49	88.5	85.5	. . . .	77.5	51.0	25.0
90	48	88.0	85.0	. . . .	77.5	50.5	24.0
88	47	87.0	84.5	. . . .	77.0	50.0	23.0

(continued)

TABLE 2 BRINELL AND EQUIVALENT ROCKWELL HARDNESS NUMBERS B, E, F AND G SCALES/ROCKWELL SUPERFICIAL (continued)

Brinell Numbers, 500 kg. Load	Rockwell B, E, F and G Scales				Rockwell Superficial		
	B Scale, 1/16 in Ball, 100 kg., Red Figures	E Scale, 1/ 8 in Ball 100 kg., Red Figures	F Scale 1/16 in Ball, 60 kg., Red Figures	G Scale, 1/16 in Ball, 150 kg., Red Figures	15-T Scale 1/16 in Ball, 15 kg., Load	30-T Scale 1/16 in Ball, 30 kg., Load	45-T Scale 1/16 in Ball, 45 kg., Load
87	46	86.5	84.0	. . . .	77.0	49.5	22.0
86	45	86.0	83.5	. . . .	76.5	49.0	21.0
85	44	85.5	83.0	. . . .	76.0	48.0	20.0
83	43	85.0	82.5	. . . .	76.0	47.5	19.0
82	42	84.5	82.0	. . . .	75.5	47.0	18.0
81	41	84.0	81.5	. . . .	75.0	46.5	17.0
80	40	83.0	81.0	. . . .	75.0	46.0	16.0
79	39	82.5	80.0	. . . .	74.5	45.0	15.0
78	38	82.0	79.5	. . . .	74.5	44.5	14.5
77	37	81.0	79.0	. . . .	74.0	44.0	13.5
76	36	80.5	78.5	. . . .	74.0	43.0	12.5
75	35	80.0	78.0	. . . .	73.5	42.5	11.5
75	34	79.5	77.5	. . . .	73.0	42.0	10.5
74	33	79.0	77.0	. . . .	73.0	41.0	9.5
74	32	78.0	76.0	. . . .	72.5	40.5	9.0
73	31	77.5	75.5	. . . .	72.0	40.0	8.0
72	30	77.0	75.0	. . . .	72.0	39.0	7.0
71	29	76.5	74.5	. . . .	71.5	38.5	6.0

(continued)

TABLE 2 BRINELL AND EQUIVALENT ROCKWELL HARDNESS NUMBERS B, E, F AND G SCALES/ROCKWELL SUPERFICIAL (continued)

Brinell Numbers, 500 kg. Load	Rockwell B, E, F and G Scales				Rockwell Superficial		
	B Scale, 1/16 in Ball, 100 kg., Red Figures	E Scale, 1/ 8 in Ball 100 kg., Red Figures	F Scale 1/16 in Ball, 60 kg., Red Figures	G Scale, 1/16 in Ball, 150 kg., Red Figures	15-T Scale 1/16 in Ball, 15 kg., Load	30-T Scale 1/16 in Ball, 30 kg., Load	45-T Scale 1/16 in Ball, 45 kg., Load
71	28	76.0	74.0	. . . .	71.5	38.0	5.0
70	27	75.0	73.5	. . . .	71.0	37.0	4.0
69	26	74.5	73.0	. . . .	71.0	36.5	3.0
68	25	73.5	72.5	. . . .	70.5	36.0	2.0
67	24	73.0	72.0	. . . .	70.0	35.0	1.0
66	23	72.0	71.5	. . . .	70.0	34.5	0
66	22	71.5	71.0	. . . .	69.5	34.0	. . . .
65	21	71.0	70.0	. . . .	69.0	33.0	. . . .
65	20	70.0	69.5	. . . .	69.0	32.5	. . . .
64	19	69.0	69.0	. . . .	68.5	32.0	. . . .
64	18	68.5	68.5	. . . .	68.5	31.0	. . . .
63	17	68.0	68.0	. . . .	68.0	30.5	. . . .
63	16	67.0	67.5	. . . .	68.0	30.0	. . . .
62	15	66.5	67.0	. . . .	67.5	29.0	. . . .
62	14	66.0	66.5	. . . .	67.0	28.0	. . . .
62	13	65.0	66.0	. . . .	67.0	27.5	. . . .
61	12	64.5	65.0	. . . .	66.5	26.5	. . . .
61	11	64.0	64.5	. . . .	66.0	25.5	. . . .

(continued)

TABLE 2 BRINELL AND EQUIVALENT ROCKWELL HARDNESS NUMBERS B, E, F AND G SCALES/ROCKWELL SUPERFICIAL (continued)

Brinell Numbers, 500 kg. Load	Rockwell B, E, F and G Scales				Rockwell Superficial		
	B Scale, 1/16 in Ball, 100 kg., Red Figures	E Scale, 1/8 in Ball 100 kg., Red Figures	F Scale 1/16 in Ball, 60 kg. Red Figures	G Scale, 1/16 in Ball, 150 kg., Red Figures	15-T Scale 1/16 in Ball, 15 kg., Load	30-T Scale 1/16 in Ball, 30 kg., Load	45-T Scale 1/16 in Ball, 45 kg., Load
60	10	63.0	64.0	. . . .	66.0	25.0	. . . .
60	9	62.0	63.5	. . . .	65.5	24.0	. . . .
59	8	61.5	63.0	. . . .	65.5	23.0	. . . .
59	7	61.0	62.5	. . . .	65.0	22.0	. . . .
58	6	60.0	62.0	. . . .	65.0	21.0	. . . .
58	5	59.5	61.5	. . . .	64.5	20.0	. . . .
58	4	58.5	60.5	. . . .	64.0	19.5	. . . .
58	3	58.0	60.0	. . . .	64.0	18.5	. . . .
57	2	57.5	59.5	. . . .	63.5	17.5	. . . .
57	1	56.5	59.0	. . . .	63.0	17.0	. . . .
. . . .	0	. . . .	. . . .	. . . .	63.0	16.0	. . . .

TABLE 3 BRINELL AND EQUIVALENT ROCKWELL HARDNESS NUMBERS C, A, AND D SCALES/ROCKWELL SUPERFICIAL

Brinell Numbers 10 mm Ball 3000 kg. Load	Rockwell C, A and D Scales			Rockwell Superficial		
	C Scale Brale Penetrator 150 kg. Load Black Figures	A Scale, Brale Penetrator, 60 kg. Black Figures	D Scale, Brale Penetrator, 100 kg., Black Figures	15-N Scale, N Brale Penetrator, 15 kg. Load	30-N Scale, N Brale Penetrator, 30 kg. Load	45-N Scale, N Brale Penetrator, 45 kg. Load
690	65	84.5	75.0	92.5	82.0	72.0
673	64	83.5	74.0	92.0	81.0	71.0
658	63	83.0	73.0	91.5	80.0	70.0
645	62	82.5	72.5	91.0	79.0	69.0
628	61	82.0	72.0	90.5	78.5	68.0
614	60	81.5	71.0	90.0	77.5	66.5
600	59	81.0	70.5	89.5	77.0	65.5
587	58	80.5	69.5	89.0	76.0	64.5
573	57	80.0	69.0	88.5	75.0	63.5
560	56	79.5	68.0	88.0	74.0	62.0
547	55	79.0	67.0	87.5	73.5	61.0
534	54	78.5	66.5	87.0	72.5	60.0
522	53	78.0	65.5	86.5	71.5	59.0
509	52	77.5	65.0	86.0	70.5	57.5
496	51	77.0	64.0	85.5	70.0	56.5
484	50	76.5	63.5	85.0	69.0	55.0
472	49	76.0	62.5	84.5	68.0	54.0

(continued)

TABLE 3 BRINELL AND EQUIVALENT ROCKWELL HARDNESS NUMBERS C, A, AND D SCALES/ROCKWELL SUPERFICIAL (continued)

Brinell Numbers 10 mm Ball 3000 kg. Load	Rockwell C, A and D Scales			Rockwell Superficial		
	C Scale Brale Penetrator, 150 kg. Load Black Figures	A Scale, Brale Penetrator, 60 kg. Black Figures	D Scale, Brale Penetrator, 100 kg., Black Figures	15-N Scale, N Brale Penetrator, 15 kg. Load	30-N Scale, N Brale Penetrator, 15 kg. Load	45-N Scale, N Brale Penetrator, 45 kg. Load
460	48	75.5	62.0	84.0	67.0	53.0
448	47	75.0	61.0	83.5	66.0	52.0
437	46	74.5	60.5	83.0	65.5	51.0
426	45	74.0	59.5	82.5	64.5	49.5
415	44	73.5	59.0	82.0	63.5	48.5
404	43	73.0	58.0	81.5	62.5	47.5
393	42	72.5	57.5	81.0	62.0	46.5
382	41	72.0	56.5	80.5	61.0	45.0
372	40	71.5	56.0	80.0	60.0	44.0
362	39	71.0	55.0	79.5	59.0	43.0
352	38	70.5	54.5	79.0	58.0	42.0
342	37	70.0	53.5	78.5	57.5	40.5
333	36	69.5	53.0	78.0	56.5	39.5
322	35	69.0	52.0	77.5	56.0	38.5
313	34	68.0	51.5	77.0	55.0	37.5
305	33	67.5	50.5	76.5	54.0	36.0
296	32	67.0	50.0	76.0	53.0	35.0

(continued)

TABLE 3 BRINELL AND EQUIVALENT ROCKWELL HARDNESS NUMBERS C, A, AND D SCALES/ROCKWELL SUPERFICIAL (continued)

Brinell Numbers 10 mm Ball 3000 kg. Load	Rockwell C, A and D Scales			Rockwell Superficial		
	C Scale Brale Penetrator, 150 kg. Load Black Figures	A Scale, Brale Penetrator, 60 kg. Black Figures	D Scale, Brale Penetrator, 100 kg., Black Figures	15-N Scale, N Brale Penetrator, 15 kg. Load	30-N Scale, N Brale Penetrator, 15 kg. Load	45-N Scale, N Brale Penetrator, 45 kg. Load
290	31	66.5	49.0	75.5	52.0	34.0
283	30	66.0	48.5	75.0	51.5	33.0
276	29	65.5	47.5	74.5	50.5	31.5
272	28	65.0	47.0	74.0	49.5	30.5
265	27	64.5	46.0	73.5	48.5	29.5
260	26	64.0	45.5	73.0	48.0	28.5
255	25	63.5	44.5	72.5	47.0	27.0
248	24	63.0	44.0	72.0	46.0	26.0
245	23	62.5	43.0	71.5	45.0	25.0
240	22	62.0	42.0	71.0	44.5	24.0
235	21	61.5	41.5	70.5	43.5	23.0
230	20	61.0	41.0	70.0	43.0	22.0

TABLE 4 TESTS SHOWING BOTH ROCKWELL AND BRINELL HARDNESS NUMBERS

Kind of Steel	Drawn to Deg F	Chemical Composition, Per Cent					Hardness	
		C	Mn	Si	P	S	Brinell 3000 kg	Rockwell C
Carbon steel quenched in brine at 1420 deg F	0	0.80	0.20	0.25	0.001	0.015	724	67.5
	340	0.80	0.20	0.25	0.001	0.015	678	64.5
	450	0.80	0.20	0.25	0.001	0.015	627	60.8
	505	0.80	0.20	0.25	0.001	0.015	599	58.1
	610	0.80	0.20	0.25	0.001	0.015	557	55.3
	755	0.80	0.20	0.25	0.001	0.015	476	49.3
	855	0.80	0.20	0.25	0.001	0.015	427	45.3
	915	0.80	0.20	0.25	0.001	0.015	389	42.2
	1000	0.80	0.20	0.25	0.001	0.015	333	36.7
	1050	0.80	0.20	0.25	0.001	0.015	310	33.9
	1175	0.80	0.20	0.25	0.001	0.015	250	25.0
	1250	0.80	0.20	0.25	0.001	0.015	221	19.1
	0	1.20	0.20	0.25	0.001	0.015	755	68.4
	310	1.20	0.20	0.25	0.001	0.015	686	67.1
	450	1.20	0.20	0.25	0.001	0.015	631	62.7
	550	1.20	0.20	0.25	0.001	0.015	587	58.6
	665	1.20	0.20	0.25	0.001	0.015	529	54.3
	755	1.20	0.20	0.25	0.001	0.015	491	51.9
	850	1.20	0.20	0.25	0.001	0.015	439	47.7
	980	1.20	0.20	0.25	0.001	0.015	352	40.5

(continued)

TABLE 4 TESTS SHOWING BOTH ROCKWELL AND BRINELL HARDNESS NUMBERS (continued)

Kind of Steel	Drawn to Deg F	Chemical Composition, Per Cent					Hardness	
		C	Mn	Si	P	S	Brinell 3000 kg.	Rockwell C
Carbon steel quenched in brine at 1420 deg F	1050	1.20	0.20	0.25	0.001	0.015	313	34.7
	1110	1.20	0.20	0.25	0.001	0.015	295	32.5
	1175	1.20	0.20	0.25	0.001	0.015	259	26.5
	1300	1.20	0.20	0.25	0.001	0.015	224	19.9
	Deg F	C	Mn	P	S	Ni	Brinell	Rc
Nickel steel 3½ per cent, quenched in water at 1600 deg F	0	0.15	0.49	0.029	0.020	3.46	394	41.9
	950	0.15	0.49	0.029	0.020	3.46	224	20.8
	1250	0.15	0.49	0.029	0.020	3.46	183	10.9
	0	0.35	0.76	0.010	0.020	3.44	516	53.0
	350	0.35	0.76	0.010	0.020	3.44	488	47.9
	650	0.35	0.76	0.010	0.020	3.44	387	39.9
	950	0.35	0.76	0.010	0.020	3.44	285	30.4
	1250	0.35	0.76	0.010	0.020	3.44	212	17.5
	Deg F	C	Mn	P	S	Cr	Brinell	Rc
Chrom.St. quenched in oil at 1500 F	950	1.01	0.22	0.026	0.024	1.33	345	37.3
	1250	1.01	0.22	0.026	0.024	1.33	284	30.1

(continued)

TABLE 4 TESTS SHOWING BOTH ROCKWELL AND BRINELL HARDNESS NUMBERS (continued)

Kind of Steel	Drawn to Deg F	Chemical Composition, Per Cent					Hardness	
		C	Mn	Si	V	Cr	Brinell 3000 kg.	Rockwell C
High chromium steel* quenched in oil at 1750 F	0	2.20	0.20	0.30	0.80	12	748	68.0
	310	2.20	0.20	0.30	0.80	12	703	65.2
	550	2.20	0.20	0.30	0.80	12	628	60.9
	850	2.20	0.20	0.30	0.80	12	574	56.3
	1000	2.20	0.20	0.30	0.80	12	538	54.3
	1050	2.20	0.20	0.30	0.80	12	506	51.9
	1130	2.20	0.20	0.30	0.80	12	456	48.1
	1175	2.20	0.20	0.30	0.80	12	433	45.4
	1235	2.20	0.20	0.30	0.80	12	401	42.8
	1265	2.20	0.20	0.30	0.80	12	377	40.7
	1300	2.20	0.20	0.30	0.80	12	342	36.8
	1330	2.20	0.20	0.30	0.80	12	330	35.1
	1380	2.20	0.20	0.30	0.80	12	301	32.1
	1440	2.20	0.20	0.30	0.80	12	269	26.9

(continued)

* The high chromium steel contains 0.50% cobalt.

TABLE 4 TESTS SHOWING BOTH ROCKWELL AND BRINELL HARDNESS NUMBERS (continued)

Kind of Steel	Drawn to Deg F	Chemical Composition, Per Cent					Hardness	
		C	Mn	P	Ni	Cr	Brinell 3000 kg.	Rockwell C
Chromium nickel steel quenched in oil at 1550 F	0	0.30	0.70	0.035	2.14	0.82	469	47.5
	350	0.30	0.70	0.035	2.14	0.82	472	48.0
	650	0.30	0.70	0.035	2.14	0.82	423	42.8
	950	0.30	0.70	0.035	2.14	0.82	321	34.2
	1250	0.30	0.70	0.035	2.14	0.82	253	25.1
	Deg F	C	Mn	Si	V	Cr	Brinell	Rc
Chromium Vanadium steel quenched in brine at 1475 F	0	0.90	0.20	0.25	0.20	0.80	709	66.1
	310	0.90	0.20	0.25	0.20	0.80	671	63.4
	450	0.90	0.20	0.25	0.20	0.80	627	59.3
	550	0.90	0.20	0.25	0.20	0.80	578	56.6
	665	0.90	0.20	0.25	0.20	0.80	538	53.6
	755	0.90	0.20	0.25	0.20	0.80	502	51.0
	850	0.90	0.20	0.25	0.20	0.80	456	47.1
	915	0.90	0.20	0.25	0.20	0.80	420	44.6
	980	0.90	0.20	0.25	0.20	0.80	401	42.9
	1050	0.90	0.20	0.25	0.20	0.80	354	38.2
	1110	0.90	0.20	0.25	0.20	0.80	325	34.7

(continued)

TABLE 4 TESTS SHOWING BOTH ROCKWELL AND BRINELL HARDNESS NUMBERS (continued)

Kind of Steel	Drawn to Deg F	Chemical Composition, Per Cent					Hardness	
		C	Mn	Si	V	Cr	Brinell 3000 kg.	Rockwell C
Chromium Vanadium steel quenched in brine at 1475 F	1175	0.90	0.20	0.25	0.20	0.80	290	31.0
	1215	0.90	0.20	0.25	0.20	0.80	259	26.2
	1300	0.90	0.20	0.25	0.20	0.80	236	22.3
	1330	0.90	0.20	0.25	0.20	0.80	224	20.4
	Deg F	C	Mn	Cr	V	W	Brinell	Rc
High speed steel quenched in oil at 2330 F	0	0.68	0.20	4	1	18	709	66.2
	1100	0.68	0.20	4	1	18	698	63.3
	1200	0.68	0.20	4	1	18	657	60.7
	1235	0.68	0.20	4	1	18	611	57.3
	1265	0.68	0.20	4	1	18	547	53.0
	1300	0.68	0.20	4	1	18	500	49.9
	1330	0.68	0.20	4	1	18	444	45.5
	1360	0.68	0.20	4	1	18	403	42.7
	1420	0.68	0.20	4	1	18	368	39.0
	1480	0.68	0.20	4	1	18	313	33.8

The high speed steel contains 0.32% silicon

(continued)

19 The Rockwell hardness test. (Refer to BS 891 , Parts 1 and 2). This is a method of determining the hardness of the material under test by indenting with a hard steel ball, or diamond cone, under a specified load. The depth of penetration is then measured.

20 The Vickers Diamond Pyramid hardness test. (Refer to BS.427, Parts 1 and 2). This is a method for determining the hardness of the metal under test by indenting with a diamond pyramid under a specified load. The size of the impression produced is then measured.

IMPACT TESTING

21 Impact tests are performed to determine the brittleness of materials such as cast iron and heat treated steels. The two approved methods are detailed in para. 22 and 23.

22 The Izod Impact test (Refer to BS.131 Part 1). The test specimen (fig.1) is prepared to the correct length and cross-section, and a notch of known depth cut. The specimen is held in a vice, and struck on the end by a striker mounted on a pendulum of standard weight and length. The energy absorbed in fracture is then calculated from the height to which the pendulum rises as it continues its swing, and is referred to as the Izod value.

23 The Charpy V-notch impact test. (Refer to BS.131 Part 2). This is defined as a notched bar impact test, in which the notched specimen, fixed at both ends, is stuck behind the notch by a striker carried on a pendulum. The energy absorbed in fracture is measured by the height to which the pendulum rises.

HEAT EFFECTS

24 Heat applied during production and subsequent heat treatment has a decided influence on the characteristics, properties and performance of metals and alloys. Such heat, especially at certain critical temperatures usually produces changes in the structure of the material.

25 Examples of such structural changes are particularly noticeable in the cases of cast iron, certain mild steels, tool steels and duralumin.

26 Internal stresses may be induced by casting, cold working, uneven sections and rapid or uneven cooling. Such stresses may be reduced, or removed, by various forms of heat-treatments, which depend for their effect on plasticity which occurs when:

26.1 The correct amount of heat is applied at specified rates and for specified times. For example, steel should not be placed cold in a highly heated furnace, but the furnace temperature slowly raised and maintained, to allow the heat to reach the centre of the metal.

26.2 The heating medium and gases, evolved within the furnace, may affect heated material by carburising or oxidising it, with consequent weakness of the material due to excessive grain growth.

26.3 To reduce these effects, heat treatment baths of the liquid type, utilising water, oil, lead, lead and tin, and salt, cover a wide temperature range for various metal and alloy types.

27 Prior to any operation or process involving the application of heat to metals, the character of the metal or alloy is to be ascertained, and the heating process (applicable to that material) verified.

Note ...

Metal exposed to excessive heat cannot be restored to its former state by heat treatment, and must be scrapped.

THERMOMETRY

28 In order to obtain the necessary strict control of heat during the production (and subsequent operations to) metals and alloys, varying types of thermometric gauges are employed. Generally, they will be of the types detailed in para. 29 to 38.

Pyrometers (optical)

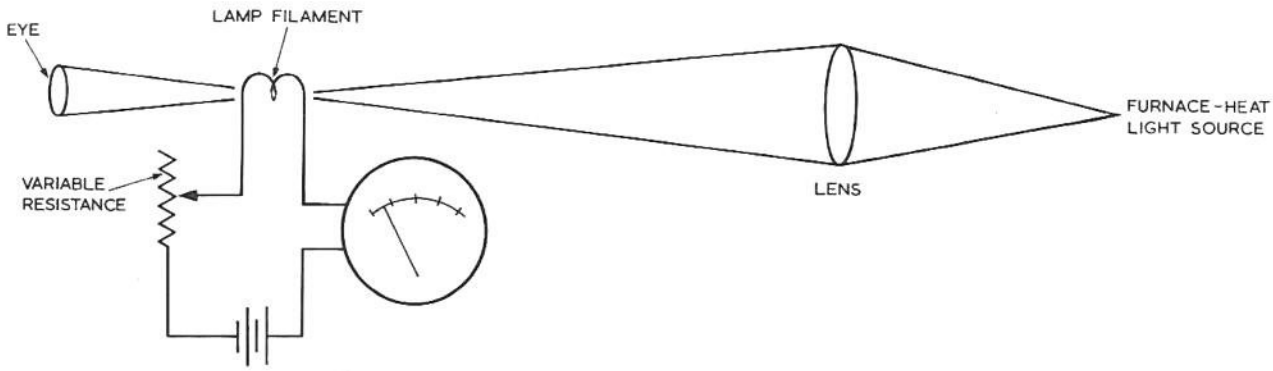


Fig. 2 Optical pyrometer (variable resistance type)

29 Optical pyrometers measure the intensity of the furnace heat by:

29.1 Estimating the colour of the radiation (of the heated object) compared with that of a suitable standard light intensity, varied by a suitable resistance (fig. 2).

29.2 Varying the furnace brilliancy by means of alterations in the position of a wedge-shaped prism which is moved until the intensity of light appears to be the same as that of a lamp filament maintained at a constant standard value, (fig. 3).

The latter types of pyrometers are seldom used for gauging temperatures below 900°C as the luminosity within the furnace below the point is difficult to match, also smoke and incandescent gases give errors in reading and readings taken may vary with individual observers.

Pyrometers (thermocouples) fig. 4)

30 Defined as the combination of apparatus forming a temperature indicating instrument whose action derives from a thermo-electric current. If two wires of suitably different metals are joined at one end and subjected to a sufficiently high temperature at that junction a small electric pressure is generated across the free ends.

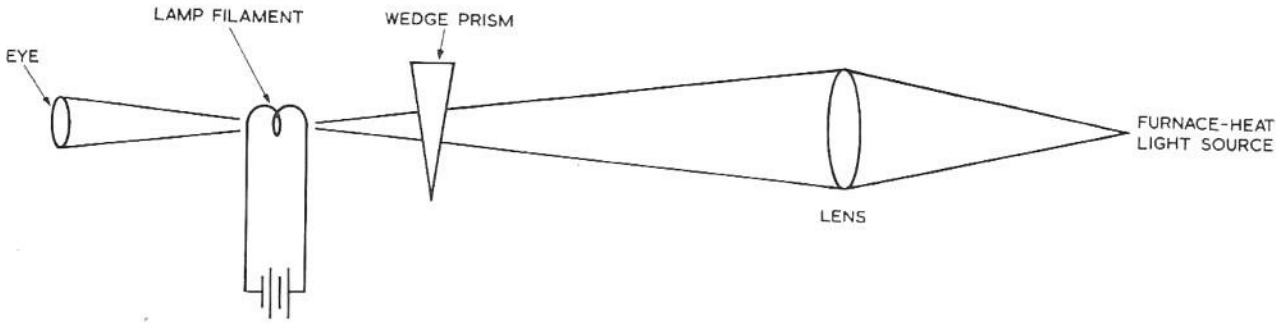


Fig. 3 Optical pyrometer (wedge prism type)

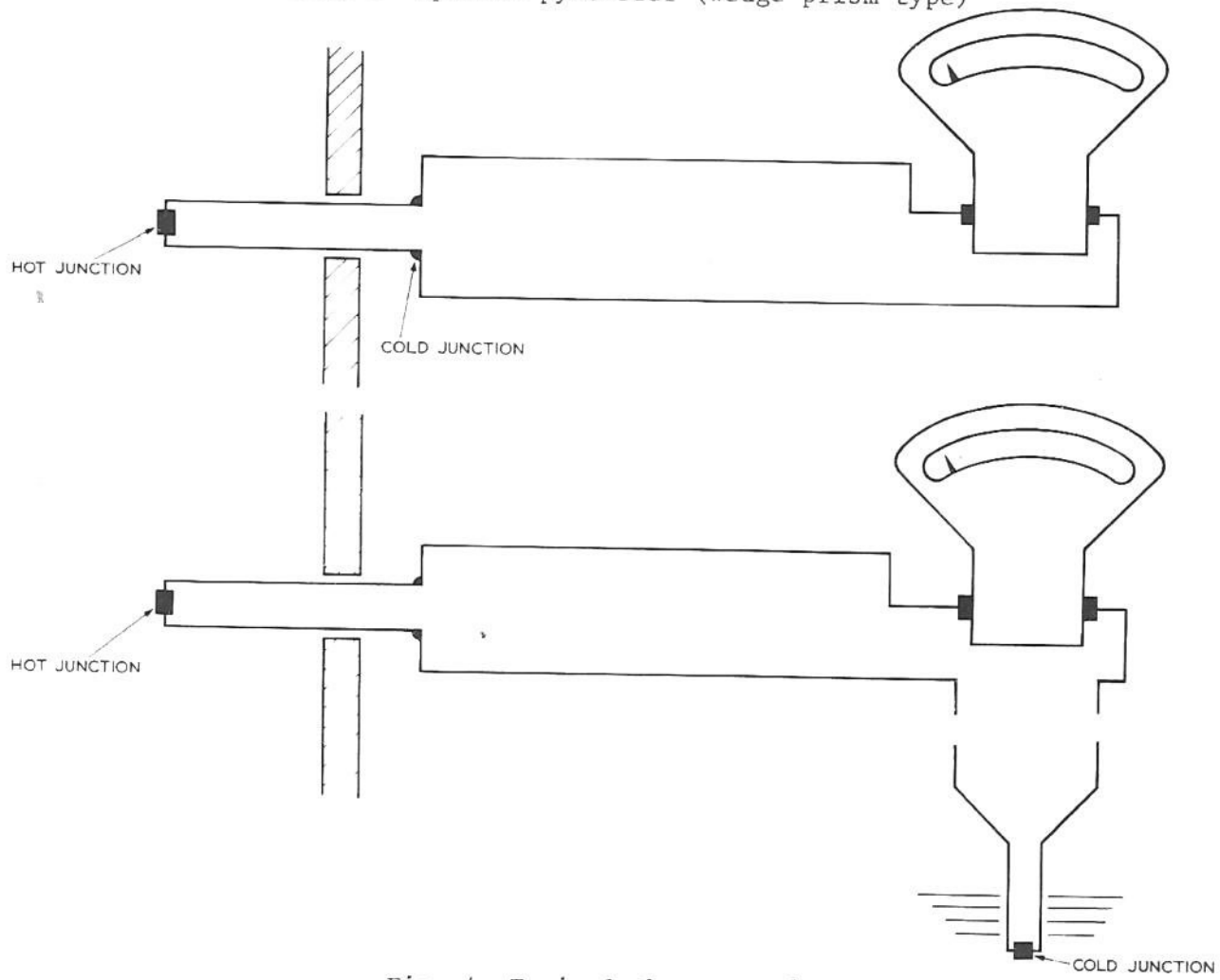


Fig. 4 Typical thermocouples

31 This pressure can then be measured by means of a milli-voltmeter with a temperature scale, the resultant reading on the scale registering the temperature changes of the heated junction whilst the free ends are maintained at a constant temperature, e.g. from 0-24°C.

32 The combination of metals most frequently used in instruments registering temperatures up to 1650°C is a platinum wire with an alloy wire of platinum and 10 to 15 per cent rhodium. For the protection of the platinum wires against the higher temperatures, the hot junction may be enclosed in a porcelain or ceramic tube; the thermo-couple in use should not come into contact with the flames otherwise the temperature reading shown on the scale will be higher than the true furnace heat.

Pyrometric cones

33 These may be referred to as Seger, fusion cones or sentinels. Composed of clay and oxide mixtures, and made in triangular pyramidic form, the cones are graded, each grade being numbered in order, to indicate small increases in the fusing points of the cones to temperatures in the region of 2000°C. When the calibrated temperature of a cone is reached, it softens and bends over.

34 The cones can be selected (in combination) to indicate:

34.1 The temperature required for the work piece.

34.2 A cone of slightly lower fusing point used as a warning that the critical temperature has been almost reached.

34.3 A cone indicating the maximum safe temperature for the work in hand beyond which the work must not be heated.

Pyrometers (radiation)

35 This method is based on the fact that the temperature of a body may be deduced from the amount of thermal radiation it produces.

36 An important advantage lies in the face that the instrument can be located outside the hot zone, and can be used when:

36.1 The sight path is obscured by steam, smoke or dust particles.

36.2 The size of the heat source varies.

37 When used with photoelectric sensing equipment, the temperature of moving bodies can be measured at high speeds e.g., as in a steel rolling mill.

38 There are two main types of radiation pyrometers;

38.1 Visual. These depend on producing visual photometric match between the intensity of radiation from a standard or reference source, and the intensity of radiation from the body being measured.

38.2 Objective. There are four main sub-types, viz.

38.2.1 Direct reading.

38.2.2 Comparison

38.2.3 Ratio

38.2.4 Emissivity compensated.

39 In such instruments, the comparison between the standard (or reference source) and the body being measured, takes place usually on a time, rather than a space-sharing basis. (See also BS.1041 : Part 5 : 1972).