LAMPIRAN

Komposisi kimia baja tuang perkakas hasil prose pengecoran yang mengacu pada JIS SKD 11

No.	Alloy	C	Si	Mn	P	S	Cr	Mo
		%	%	%	%	%	%	%
1	E	0,505	0,624	0,695	0,0165	0,0101	1,614	0,3102
2	D	0,563	0,52	0,604	0,0179	0,0157	1,603	0,465
3	A	0,546	0,884	1,077	0,0162	0,0071	1,581	0,4206
4	B	0,502	2,078	1,015	0,0163	0,0119	1,563	0,4464
5	C	0,4857	3,081	1,001	0,0165	0,0134	1,548	0,4267

No.	Alloy	Ni	Al	Co	Cu	Nb	Ti	V
		%	%	%	%	%	%	%
1	E	0,0536	0,0046	0,0045	0,0199	0,0043	0,0023	0,009
2	D	0,0597	0,0214	0,0038	0,697	0,0021	0,0021	0,131
3	A	0,1941	0,02	0,0042	0,84	0,0026	0,0036	0,1239
4	B	0,1866	0,1018	0,0039	0,812	0,0023	0,0047	0,1257
5	C	0,1769	0,1065	0,0035	0,726	0,0022	0,0057	0,1201

No.	Alloy	W	Pb	Sn	As	Ca	Ce	Se
		%	%	%	%	%	%	%
1	E	<0,01	<0,001	0,0004	0,0029	0,0017	<0,002	<0,005
2	D	<0,02	0,0034	<0,0004	0,0032	0,0003	<0,003	<0,006
3	A	<0,03	0,0047	0,0005	0,0027	0,0039	<0,004	<0,007
4	B	<0,04	0,0019	0,0005	0,0025	>0,0072	<0,005	<0,008
5	C	<0,05	0,0013	0,0009	0,0025	>0,0072	<0,006	<0,009

No.	Alloy	Ta	B	N	Fe
		%	%	%	%
1	E	0,0112	0,0011	0,0043	96,1
2	D	0,0145	0,0012	0,0059	95,3
3	A	0,0127	0,0013	0,0023	94,3
4	B	0,0126	0,0012	0,0028	93,1
5	C	0,0113	0,002	0,0008	92,3

Data pengujian kekerasan permukaan sampel As-Cast

Sample A					
d1	d2	dr	HV		HRC
0.0615	0.0625	0.062	482.3101		
0.0645	0.0645	0.0645	445.6463	459.0258	46
0.066	0.0625	0.06425	449.1211		
Sample B					
d1	d2	dr	HV		HRC
0.06	0.056	0.058	551.1296		
0.06	0.061	0.0605	506.5228	534.6871	51
0.0585	0.058	0.05825	546.409		
Sample C					
d1	d2	dr	HV		HRC
0.052	0.0535	0.05275	666.2923		
0.053	0.053	0.053	660.0214	672.8684	59
0.051	0.0525	0.05175	692.2915		

Data pengujian kekerasan permukaan sampel speroidisasi anil

Sampel	d1	d2	d rata	HV	HV rata2
A	0.0865	0.0867	0.0866	247.2145	249.4257
	0.0828	0.0825	0.08265	271.4089	
	0.0885	0.0912	0.08985	229.6538	
B	0.0876	0.0908	0.0892	233.0129	229.573
	0.0868	0.089	0.0879	239.9562	
	0.0939	0.0915	0.0927	215.7497	
C	0.0845	0.081	0.08275	270.7533	267.9576
	0.0818	0.0844	0.0831	268.4774	
	0.084	0.0834	0.0837	264.642	

Data pengujian kekerasan permukaan sampel hasil tempering 640°C

sampel	d1	d2	d rata	HV	HV rata2
A	0.0705	0.072	0.07125	365.2078	359.7381
	0.0737	0.0719	0.0728	349.8219	
	0.072	0.0707	0.07135	364.1848	
B	0.093	0.0908	0.0919	219.5223	240.5953
	0.0812	0.0832	0.0822	274.3886	
	0.0901	0.0903	0.0902	227.875	
C	0.0805	0.081	0.08075	284.3313	293.6811
	0.078	0.074	0.076	320.9834	
	0.0835	0.0805	0.082	275.7287	

Data pengujian kekerasan sampel A setelah flame hardening

Sampel A					
No.	d1	d2	dr	HV	HRC
1	0.051	0.056	0.0535	647.7422	58
2	0.055	0.058	0.0565	580.7816	54
3	0.055	0.058	0.0565	580.7816	54
4	0.057	0.057	0.057	570.6371	54
5	0.057	0.058	0.0575	560.7561	53
6	0.058	0.0575	0.05775	555.9116	53
7	0.057	0.059	0.058	551.1296	52
8	0.055	0.061	0.058	551.1296	52
9	0.0565	0.06	0.05825	546.409	52
10	0.0585	0.061	0.05975	519.3186	50
11	0.06	0.0605	0.06025	510.735	50
12	0.058	0.0625	0.06025	510.735	50
13	0.062	0.059	0.0605	506.5228	49
14	0.0595	0.0615	0.0605	506.5228	49
15	0.0605	0.062	0.06125	494.1941	49
16	0.061	0.062	0.0615	490.1844	48
17	0.061	0.063	0.062	482.3101	48
18	0.061	0.064	0.0625	474.624	47
19	0.061	0.0645	0.06275	470.8497	47
20	0.062	0.064	0.063	467.1202	47
21	0.066	0.066	0.066	425.6198	43
22	0.068	0.067	0.0675	406.9136	41
23	0.069	0.069	0.069	389.414	40
24	0.07	0.07	0.07	378.3673	39
25	0.0705	0.07	0.07025	375.6791	38
26	0.071	0.071	0.071	367.7842	38
27	0.074	0.073	0.0735	343.1903	35
28	0.072	0.081	0.0765	316.8012	32
29	0.076	0.0795	0.07775	306.6966	31
30	0.0765	0.08	0.07825	302.7897	30

Data pengujian kekerasan sampel B setelah flame hardening

Sampel B					
No.	d1	d2	dr	HV	HRC
1	0.05	0.048	0.049	772.1783	63
2	0.05	0.05	0.05	741.6	62
3	0.05	0.0535	0.05175	692.2915	60
4	0.054	0.054	0.054	635.8025	57
5	0.0545	0.0545	0.0545	624.1899	57
6	0.058	0.058	0.058	551.1296	52
7	0.058	0.059	0.0585	541.7488	52
8	0.061	0.061	0.061	498.2532	49
9	0.061	0.061	0.061	498.2532	49
10	0.062	0.0611	0.06155	489.3883	48
11	0.062	0.062	0.062	482.3101	48
12	0.062	0.062	0.062	482.3101	48
13	0.062	0.062	0.062	482.3101	48
14	0.065	0.06	0.0625	474.624	47
15	0.06	0.065	0.0625	474.624	47
16	0.06	0.0655	0.06275	470.8497	47
17	0.064	0.064	0.064	452.6367	45
18	0.064	0.064	0.064	452.6367	45
19	0.064	0.065	0.0645	445.6463	45
20	0.064	0.065	0.0645	445.6463	45
21	0.065	0.064	0.0645	445.6463	45
22	0.0655	0.065	0.06525	435.4604	44
23	0.068	0.063	0.0655	432.1426	44
24	0.064	0.067	0.0655	432.1426	44
25	0.0655	0.0655	0.0655	432.1426	44
26	0.067	0.065	0.066	425.6198	43
27	0.0665	0.0665	0.0665	419.2436	43
28	0.0655	0.068	0.06675	416.1091	42
29	0.065	0.07	0.0675	406.9136	41
30	0.068	0.068	0.068	400.9516	41

Data pengujian sampel C setelah flame hardening

Sampel C					
No.	d1	d2	dr	HV	HRC
1	0.047	0.047	0.047	839.2938	65
2	0.047	0.051	0.049	772.1783	63
3	0.05	0.05	0.05	741.6	62
4	0.05	0.05	0.05	741.6	62
5	0.048	0.053	0.0505	726.9876	61
6	0.0505	0.0525	0.0515	699.0291	60
7	0.052	0.052	0.052	685.6509	60
8	0.052	0.052	0.052	685.6509	60
9	0.054	0.05	0.052	685.6509	60
10	0.051	0.054	0.0525	672.6531	59
11	0.0535	0.0525	0.053	660.0214	58
12	0.054	0.0525	0.05325	653.8385	58
13	0.052	0.0555	0.05375	641.7307	57
14	0.054	0.054	0.054	635.8025	57
15	0.054	0.055	0.0545	624.1899	57
16	0.055	0.055	0.055	612.8926	56
17	0.055	0.055	0.055	612.8926	56
18	0.054	0.0565	0.05525	607.3586	56
19	0.056	0.056	0.056	591.199	55
20	0.057	0.057	0.057	570.6371	54
21	0.057	0.057	0.057	570.6371	54
22	0.056	0.058	0.057	570.6371	54
23	0.057	0.057	0.057	570.6371	54
24	0.057	0.057	0.057	570.6371	54
25	0.057	0.057	0.057	570.6371	54
26	0.0575	0.0575	0.0575	560.7561	53
27	0.057	0.061	0.059	532.6056	51
28	0.06	0.0615	0.06075	502.3624	49
29	0.062	0.062	0.062	482.3101	48
30	0.063	0.061	0.062	482.3101	48

Designation: E 140 – 02

Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, and Scleroscope Hardness[1]

This standard is issued under the fixed designation E 140; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 Conversion Table 1 presents data in the Rockwell C hardness range on the relationship among Brinell hardness, Vickers hardness, Rockwell hardness, Rockwell superficial hardness, Knoop hardness, and Scleroscope hardness of non-austenitic steels including carbon, alloy, and tool steels in the as-forged, annealed, normalized, and quenched and tempered conditions provided that they are homogeneous.

1.2 Conversion Table 2 presents data in the Rockwell B hardness range on the relationship among Brinell hardness, Vickers hardness, Rockwell hardness, Rockwell superficial hardness, Knoop hardness, and Scleroscope hardness of non-austenitic steels including carbon, alloy, and tool steels in the as-forged, annealed, normalized, and quenched and tempered conditions provided that they are homogeneous.

1.3 Conversion Table 3 presents data on the relationship among Brinell hardness, Vickers hardness, Rockwell hardness, Rockwell superficial hardness, and Knoop hardness of nickel and high-nickel alloys (nickel content over 50 %). These hardness conversion relationships are intended to apply particularly to the following: nickel-aluminum-silicon specimens finished to commercial mill standards for hardness testing, covering the entire range of these alloys from their annealed to their heavily cold-worked or age-hardened conditions, including their intermediate conditions.

1.4 Conversion Table 4 presents data on the relationship among Brinell hardness, Vickers hardness, Rockwell hardness, and Rockwell superficial hardness of cartridge brass.

1.5 Conversion Table 5 presents data on the relationship between Brinell hardness and Rockwell B hardness of austenitic stainless steel plate in the annealed condition.

1.6 Conversion Table 6 presents data on the relationship between Rockwell hardness and Rockwell superficial hardness of austenitic stainless steel sheet.

1.7 Conversion Table 7 presents data on the relationship among Brinell hardness, Vickers hardness, Rockwell hardness, Rockwell superficial hardness, and Knoop hardness of copper.

1.8 Conversion Table 8 presents data on the relationship among Brinell hardness, Rockwell hardness, and Vickers hardness of alloyed white iron.

1.9 Conversion Table 9 presents data on the relationship among Brinell hardness, Vickers hardness, Rockwell hardness, and Rockwell superficial hardness of wrought aluminum products.

1.10 Many of the conversion values presented herein were obtained from computer-generated curves of actual test data. Most Rockwell hardness numbers are presented to the nearest 0.1 or 0.5 hardness number to permit accurate reproduction of these curves. Since all converted hardness values must be considered approximate, however, all converted Rockwell hardness numbers shall be rounded to the nearest whole number in accordance with Practice E 29.

1.11 Appendix X1-Appendix X9 contain equations developed from the data in Tables 1-9, respectively, to convert from one hardness scale to another. Since all converted hardness values must be considered approximate, however, all converted hardness numbers shall be rounded in accordance with Practice E 29.

1.12 Conversion of hardness values should be used only when it is impossible to test the material under the conditions specified, and when conversion is made it should be done with discretion and under controlled conditions. Each type of hardness test is subject to certain errors, but if precautions are carefully observed, the reliability of hardness readings made on instruments of the indentation type will be found comparable. Differences in sensitivity within the range of a given hardness scale (for example, Rockwell B) may be greater than between two different scales or types of instruments. The conversion values, whether from the tables or calculated from the equations, are only approximate and may be inaccurate for specific application.

2. Referenced Documents

2.1 *ASTM Standards:*

[1] These conversion tables are under the jurisdiction of ASTM Committee E28 on Mechanical Testing and are the direct responsibility of Subcommittee E28.06 on Indentation Hardness Testing.

Current edition approved Jan. 10, 2002. Published February 2002. Originally published as E 140 – 58. Last previous edition E 140 – 97[ε1].

E 10 Test Method for Brinell Hardness of Metallic Materials[2]
E 18 Test Method for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials[2]
E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications[3]
E 92 Test Method for Vickers Hardness of Metallic Materials[2]
E 384 Test Method for Microhardness of Materials[2]
E 448 Practice for Scleroscope Hardness Testing of Metallic Materials[2]

3. Methods for Hardness Determinations

3.1 The hardness readings used with these conversion tables shall be determined in accordance with one of the following ASTM test methods:

3.1.1 *Vickers Hardness*—Test Method E 92.

3.1.2 *Brinell Hardness*—Test Method E 10.

3.1.3 *Rockwell Hardness*—Test Method E 18 Scales A, B, C, D, E, F, G, H, K, 15-N, 30-N, 45-N, 15-T, 30-T, 45-T, 15-W.

3.1.4 *Knoop Hardness*—Test Method E 384.

3.1.5 *Scleroscope* [4] *Hardness*—Practice E 448.

4. Apparatus and Reference Standards

4.1 The apparatus and reference standards shall conform to the description in Test Methods E 92, E 10, E 18, E 384, and Practice E 448.

5. Principle of Method of Conversion

5.1 Tests have proved that even the most reliable data cannot be fitted to a single conversion relationship for all metals. Indentation hardness is not a single fundamental property but a combination of properties, and the contribution of each to the hardness number varies with the type of test. The modulus of elasticity has been shown to influence conversions at high hardness levels; and at low hardness levels conversions between hardness scales measuring depth and those measuring diameter are likewise influenced by differences in the modulus of elasticity. Therefore separate conversion tables are necessary for different materials.

NOTE 1—Hardness conversion values for other metals based on comparative test on similar materials having similar mechanical properties will be added to this standard as the need arises.

6. Significance and Use

6.1 The conversion values given in the tables, or calculated by the equations given in the appendixes, should only be considered valid for the specific materials indicated. This is because conversions can be affected by several factors, including the material alloy, grain structure, heat treatment, etc.

6.2 Since the various types of hardness tests do not all measure the same combination of material properties, conversion from one hardness scale to another is only an approximate process. Because of the wide range of variation among different materials, it is not possible to state confidence limits for the errors in using a conversion chart. Even in the case of a table established for a single material, such as the table for cartridge brass, some error is involved depending on composition and methods of processing (see Appendix X1).

6.3 Because of their approximate nature, conversion tables must be regarded as only an estimate of comparative values. It is recommended that hardness conversions be applied primarily to values such as specification limits, which are established by agreement or mandate, and that the conversion of test data be avoided whenever possible.

7. Reporting of Hardness Numbers

7.1 When reporting converted hardness numbers the measured hardness and test scale shall be indicated in parentheses as in the following example:

$$353\ HBW\ (38\ HRC) \quad (1)$$

8. Keywords

8.1 conversion; hardness scale; metallic

[2] *Annual Book of ASTM Standards*, Vol 03.01.
[3] *Annual Book of ASTM Standards*, Vol 14.02.
[4] Registered trademark of the Shore Instrument and Manufacturing Co., Inc.

TABLE 1 Approximate Hardness Conversion Numbers for Non-Austenitic Steels (Rockwell C Hardness Range)[A, B]

Rockwell C Hardness Number 150 kgf (HRC)	Vickers Hardness Number (HV)	Brinell Hardness Number[C] 10-mm Standard Ball, 3000-kgf (HBS)	Brinell Hardness Number[C] 10-mm Carbide Ball, 3000-kgf (HBW)	Knoop Hardness, Number 500-gf and Over (HK)	Rockwell Hardness Number A Scale, 60-kgf (HRA)	Rockwell Hardness Number D Scale, 100-kgf (HRD)	Rockwell Superficial Hardness Number 15-N Scale, 15-kgf (HR 15-N)	Rockwell Superficial Hardness Number 30-N Scale, 30-kgf (HR 30-N)	Rockwell Superficial Hardness Number 45-N Scale, 45-kgf (HR 45-N)	Scleroscope Hardness Number[D]	Rockwell C Hardness Number 150 kgf (HRC)
68	940	...	...	920	85.6	76.9	93.2	84.4	75.4	97.3	68
67	900	...	...	895	85.0	76.1	92.9	83.6	74.2	95.0	67
66	865	...	...	870	84.5	75.4	92.5	82.8	73.3	92.7	66
65	832	...	(739)	846	83.9	74.5	92.2	81.9	72.0	90.6	65
64	800	...	(722)	822	83.4	73.8	91.8	81.1	71.0	88.5	64
63	772	...	(705)	799	82.8	73.0	91.4	80.1	69.9	86.5	63
62	746	...	(688)	776	82.3	72.2	91.1	79.3	68.8	84.5	62
61	720	...	(670)	754	81.8	71.5	90.7	78.4	67.7	82.6	61
60	697	...	(654)	732	81.2	70.7	90.2	77.5	66.6	80.8	60
59	674	...	634	710	80.7	69.9	89.8	76.6	65.5	79.0	59
58	653	...	615	690	80.1	69.2	89.3	75.7	64.3	77.3	58
57	633	...	595	670	79.6	68.5	88.9	74.8	63.2	75.6	57
56	613	...	577	650	79.0	67.7	88.3	73.9	62.0	74.0	56
55	595	...	560	630	78.5	66.9	87.9	73.0	60.9	72.4	55
54	577	...	543	612	78.0	66.1	87.4	72.0	59.8	70.9	54
53	560	...	525	594	77.4	65.4	86.9	71.2	58.6	69.4	53
52	544	(500)	512	576	76.8	64.6	86.4	70.2	57.4	67.9	52
51	528	(487)	496	558	76.3	63.8	85.9	69.4	56.1	66.5	51
50	513	(475)	481	542	75.9	63.1	85.5	68.5	55.0	65.1	50
49	498	(464)	469	526	75.2	62.1	85.0	67.6	53.8	63.7	49
48	484	451	455	510	74.7	61.4	84.5	66.7	52.5	62.4	48
47	471	442	443	495	74.1	60.8	83.9	65.8	51.4	61.1	47
46	458	432	432	480	73.6	60.0	83.5	64.8	50.3	59.8	46
45	446	421	421	466	73.1	59.2	83.0	64.0	49.0	58.5	45
44	434	409	409	452	72.5	58.5	82.5	63.1	47.8	57.3	44
43	423	400	400	438	72.0	57.7	82.0	62.2	46.7	56.1	43
42	412	390	390	426	71.5	56.9	81.5	61.3	45.5	54.9	42
41	402	381	381	414	70.9	56.2	80.9	60.4	44.3	53.7	41
40	392	371	371	402	70.4	55.4	80.4	59.5	43.1	52.6	40
39	382	362	362	391	69.9	54.6	79.9	58.6	41.9	51.5	39
38	372	353	353	380	69.4	53.8	79.4	57.7	40.8	50.4	38
37	363	344	344	370	68.9	53.1	78.8	56.8	39.6	49.3	37
36	354	336	336	360	68.4	52.3	78.3	55.9	38.4	48.2	36
35	345	327	327	351	67.9	51.5	77.7	55.0	37.2	47.1	35
34	336	319	319	342	67.4	50.8	77.2	54.2	36.1	46.1	34
33	327	311	311	334	66.8	50.0	76.6	53.3	34.9	45.1	33
32	318	301	301	326	66.3	49.2	76.1	52.1	33.7	44.1	32
31	310	294	294	318	65.8	48.4	75.6	51.3	32.5	43.1	31
30	302	286	286	311	65.3	47.7	75.0	50.4	31.3	42.2	30
29	294	279	279	304	64.8	47.0	74.5	49.5	30.1	41.3	29
28	286	271	271	297	64.3	46.1	73.9	48.6	28.9	40.4	28
27	279	264	264	290	63.8	45.2	73.3	47.7	27.8	39.5	27
26	272	258	258	284	63.3	44.6	72.8	46.8	26.7	38.7	26
25	266	253	253	278	62.8	43.8	72.2	45.9	25.5	37.8	25
24	260	247	247	272	62.4	43.1	71.6	45.0	24.3	37.0	24
23	254	243	243	266	62.0	42.1	71.0	44.0	23.1	36.3	23
22	248	237	237	261	61.5	41.6	70.5	43.2	22.0	35.5	22
21	243	231	231	256	61.0	40.9	69.9	42.3	20.7	34.8	21
20	238	226	226	251	60.5	40.1	69.4	41.5	19.6	34.2	20

[A] In the table headings, *force* refers to total test forces.

[B] Appendix X1 contains equations converting determined hardness scale numbers to Rockwell C hardness numbers for non-austenitic steels. Refer to 1.11 before using conversion equations.

[C] The Brinell hardness numbers in parentheses are outside the range recommended for Brinell hardness testing in 8.1 of Test Method E 10.

[D] These Scleroscope hardness conversions are based on Vickers—Scleroscope hardness relationships developed from Vickers hardness data provided by the National Bureau of Standards for 13 steel reference blocks, Scleroscope hardness values obtained on these blocks by the Shore Instrument and Mfg. Co., Inc., the Roll Manufacturers Institute, and members of this Institute, and also on hardness conversions previously published by the American Society for Metals and the Roll Manufacturers Institute.

Designation: E 92 – 82 (Reapproved 2003)$^{\epsilon 2}$

Standard Test Method for Vickers Hardness of Metallic Materials[1]

This standard is issued under the fixed designation E 92; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

ϵ^1 NOTE—Section 3.2 was editorially updated in June 2003.
ϵ^2 NOTE—Table 3 was editorially corrected in June 2004.

1. Scope

1.1 This test method covers the determination of the Vickers hardness of metallic materials, using applied forces of 1 kgf to 120 kgf,[2] the verification of Vickers hardness testing machines (Part B), and the calibration of standardized hardness test blocks (Part C). Two general classes of standard tests are recognized:

1.1.1 *Verification, Laboratory, or Referee Tests*, where a high degree of accuracy is required.

1.1.2 *Routine Tests*, where a somewhat lower degree of accuracy is permissible.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 4 Practices for Force Verification of Testing Machines[3]

E 140 Hardness Conversion Tables for Metals (Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Rockwell Superficial Hardness, Knoop Hardness, and Scleroscope Hardness)[3]

E 384 Test Method for Microindentation Hardness of Materials[3]

3. Terminology

3.1 *calibration*—determination of the values of the significant parameters by comparison with values indicated by a reference instrument or by a set of reference standards.

3.2 *verification*—confirmation by examination and provision of evidence that an instrument, material, reference, or standard is in conformance with a specification.

3.3 *Vickers hardness number, HV*—a number related to the applied force and the surface area of the permanent impression made by a square-based pyramidal diamond indenter having included face angles of 136° (see Fig. 1 and Table 1), computed from the equation:

$$HV = 2P \sin(\alpha/2)/d^2 = 1.8544P/d^2 \quad (1)$$

where:

P = force, kgf,
d = mean diagonal of impression, mm, and
α = face angle of diamond = 136°.

3.4 *Vickers hardness test*—an indentation hardness test using calibrated machines to force a square-based pyramidal diamond indenter having specified face angles, under a predetermined force, into the surface of the material under test and to measure the diagonals of the resulting impression after removal of the force.

3.4.1 Vickers hardness tests are made at test forces of 1 kgf to 120 kgf.

3.4.2 For practical purposes the Vickers hardness number is constant when a square-based diamond pyramid with a face angle of 136° is used with applied forces of 5 kgf and higher.

[1] This test method is under the jurisdiction of ASTM Committee E28 on Mechanical Testing and is the direct responsibility of Subcommittee E28.06 on Indentation Hardness Testing.

Current edition approved Jan. 10, 2003. Published April 2003. Originally approved in 1952. Last previous edition approved in 1997 as E 92 – 82 (1997)$^{\epsilon 1}$.

[2] A procedure covering Vickers tests using applied forces of 1 gf to 1000 gf (1 kgf) may be found in Test Method E 384, Test Method for Microindentation Hardness of Materials, appearing in the *Annual Book of ASTM Standards*, Vol 03.01.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

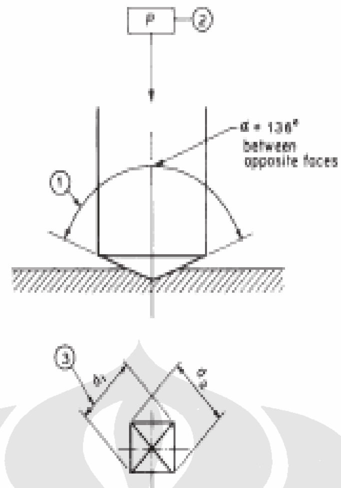

FIG. 1 Vickers Hardness Test (see Table 1)

TABLE 1 Symbols and Designations Associated with Fig. 1

Number	Symbol	Designation
1	...	Angle at the vertex of the pyramidal indenter (136°)
2	*P*	Test force in kilograms-force
3	*d*	Arithmetic mean of the two diagonals d^1 and d^2

TABLE 2 Vickers Hardness Numbers
(Diamond, 136° Face Angle, force of 1 kgf)

Diagonal of Impression, mm	Vickers Hardness Number for Diagonal Measured to 0.0001 mm									
	0.0000	0.0001	0.0002	0.0003	0.0004	0.0005	0.0006	0.0007	0.0008	0.0009
0.005	74 170	71 290	68 580	66 020	63 590	61 300	59 130	57 080	55 120	53 270
0.006	51 510	49 840	48 240	46 720	45 270	43 890	42 570	41 310	40 100	38 950
0.007	37 840	36 790	35 770	34 800	33 860	32 970	32 100	31 280	30 480	29 710
0.008	28 970	28 260	27 580	26 920	26 280	25 670	25 070	24 500	23 950	23 410
0.009	22 890	22 390	21 910	21 440	20 990	20 550	20 120	19 710	19 310	18 920
0.010	18 540	18 180	17 820	17 480	17 140	16 820	16 500	16 200	15 900	15 610
0.011	15 330	15 060	14 780	14 520	14 270	14 020	13 780	13 550	13 320	13 090
0.012	12 880	12 670	12 460	12 260	12 060	11 870	11 680	11 500	11 320	11 140
0.013	10 970	10 810	10 640	10 480	10 330	10 170	10 030	9 880	9 737	9 598
0.014	9 461	9 327	9 196	9 068	8 943	8 820	8 699	8 581	8 466	8 353
0.015	8 242	8 133	8 026	7 922	7 819	7 718	7 620	7 523	7 428	7 335
0.016	7 244	7 154	7 066	6 979	6 895	6 811	6 729	6 649	6 570	6 493
0.017	6 416	6 342	6 268	6 196	6 125	6 055	5 986	5 919	5 853	5 787
0.018	5 723	5 660	5 598	5 537	5 477	5 418	5 360	5 303	5 247	5 191
0.019	5 137	5 083	5 030	4 978	4 927	4 877	4 827	4 778	4 730	4 683
0.020	4 636	4 590	4 545	4 500	4 456	4 413	4 370	4 328	4 286	4 245
0.021	4 205	4 165	4 126	4 087	4 049	4 012	3 975	3 938	3 902	3 866
0.022	3 831	3 797	3 763	3 729	3 696	3 663	3 631	3 599	3 567	3 536
0.023	3 505	3 475	3 445	3 416	3 387	3 358	3 329	3 301	3 274	3 246
0.024	3 219	3 193	3 166	3 140	3 115	3 089	3 064	3 039	3 015	2 991
0.025	2 967	2 943	2 920	2 897	2 874	2 852	2 830	2 808	2 786	2 764
0.026	2 743	2 722	2 701	2 681	2 661	2 641	2 621	2 601	2 582	2 563
0.027	2 544	2 525	2 506	2 488	2 470	2 452	2 434	2 417	2 399	2 382
0.028	2 365	2 348	2 332	2 315	2 299	2 283	2 267	2 251	2 236	2 220
0.029	2 205	2 190	2 175	2 160	2 145	2 131	2 116	2 102	2 088	2 074
0.030	2 060	2 047	2 033	2 020	2 007	1 993	1 980	1 968	1 955	1 942
0.031	1 930	1 917	1 905	1 893	1 881	1 869	1 857	1 845	1 834	1 822
0.032	1 811	1 800	1 788	1 777	1 766	1 756	1 745	1 734	1 724	1 713
0.033	1 703	1 693	1 682	1 672	1 662	1 652	1 643	1 633	1 623	1 614

TABLE 2 *Continued*

Diagonal of Impression, mm	Vickers Hardness Number for Diagonal Measured to 0.0001 mm									
	0.0000	0.0001	0.0002	0.0003	0.0004	0.0005	0.0006	0.0007	0.0008	0.0009
0.034	1 604	1 595	1 585	1 576	1 567	1 558	1 549	1 540	1 531	1 522
0.035	1 514	1 505	1 497	1 488	1 480	1 471	1 463	1 455	1 447	1 439
0.036	1 431	1 423	1 415	1 407	1 400	1 392	1 384	1 377	1 369	1 362
0.037	1 355	1 347	1 340	1 333	1 326	1 319	1 312	1 305	1 298	1 291
0.038	1 284	1 277	1 271	1 264	1 258	1 251	1 245	1 238	1 232	1 225
0.039	1 219	1 213	1 207	1 201	1 195	1 189	1 183	1 177	1 171	1 165
0.040	1 159	1 153	1 147	1 142	1 136	1 131	1 125	1 119	1 114	1 109
0.041	1 103	1 098	1 092	1 087	1 082	1 077	1 072	1 066	1 061	1 056
0.042	1 051	1 046	1 041	1 036	1 031	1 027	1 022	1 017	1 012	1 008
0.043	1 003	998	994	989	985	980	975	971	967	962
0.044	958	953	949	945	941	936	932	928	924	920
0.045	916	912	908	904	900	896	892	888	884	880
0.046	876	873	869	865	861	858	854	850	847	843
0.047	839	836	832	829	825	822	818	815	812	808
0.048	805	802	798	795	792	788	785	782	779	775
0.049	772	769	766	763	760	757	754	751	748	745
0.050	742	739	736	733	730	727	724	721	719	716
0.051	713	710	707	705	702	699	696	694	691	688
0.052	686	683	681	678	675	673	670	668	665	663
0.053	660	658	655	653	650	648	645	643	641	638
0.054	636	634	631	629	627	624	622	620	617	615
0.055	613	611	609	606	604	602	600	598	596	593
0.056	591	589	587	585	583	581	579	577	575	573
0.057	571	569	567	565	563	561	559	557	555	553
0.058	551	549	547	546	544	542	540	538	536	535
0.059	533	531	529	527	526	524	522	520	519	516.8
0.060	515.1	513.4	511.7	510.0	508.3	506.6	505.0	503.3	501.6	500.0
0.061	498.4	496.7	495.1	493.5	491.9	490.3	488.7	487.1	485.5	484.0
0.062	482.4	480.9	479.3	477.8	476.2	474.7	473.2	471.7	470.2	468.7
0.063	467.2	465.7	464.3	462.8	461.3	459.9	458.4	457.0	455.6	454.1
0.064	452.7	451.3	449.9	448.5	447.1	445.7	444.4	443.0	441.6	440.3
0.065	438.9	437.6	436.2	434.9	433.6	432.2	430.9	429.6	428.3	427.0
0.066	425.7	424.4	423.1	421.9	420.6	419.3	418.1	416.8	415.6	414.3
0.067	413.1	411.9	410.6	409.4	408.2	407.0	405.8	404.6	403.4	402.2
0.068	401.0	399.9	398.7	397.5	396.6	395.2	394.0	392.9	391.8	390.6
0.069	389.5	388.4	387.2	386.1	385.0	383.9	382.8	381.7	380.6	379.5
0.070	378.4	377.4	376.3	375.2	374.2	373.1	372.0	371.0	369.9	368.9
0.071	367.9	366.8	365.8	364.8	363.7	362.7	361.7	360.7	359.7	358.7
0.072	357.7	356.7	355.7	354.7	353.8	352.8	351.8	350.9	349.9	348.9
0.073	348.0	347.0	346.1	345.1	344.2	343.3	342.3	341.4	340.5	339.6
0.074	338.6	337.7	336.8	335.9	335.0	334.1	333.2	332.3	331.4	330.5
0.075	329.7	328.8	327.9	327.0	326.2	325.3	324.5	323.6	322.7	321.9
0.076	321.0	320.2	319.4	318.5	317.7	316.9	316.0	315.2	314.4	313.6
0.077	312.8	312.0	311.1	310.3	309.5	308.7	307.9	307.2	306.4	305.6
0.078	304.8	304.0	303.2	302.5	301.7	300.9	300.2	299.4	298.6	297.9
0.079	297.1	296.4	295.6	294.9	294.1	293.4	292.7	291.9	291.2	290.5
0.080	289.7	289.0	288.3	287.6	286.9	286.2	285.4	284.7	284.0	283.3
0.081	282.6	281.9	281.2	280.6	279.9	279.2	278.5	277.8	277.1	276.5
0.082	275.8	275.1	274.4	273.8	273.1	272.4	271.8	271.1	270.5	269.8
0.083	269.2	268.5	267.9	267.2	266.6	266.0	265.3	264.7	264.1	263.4
0.084	262.8	262.2	261.6	260.9	260.3	259.7	259.1	258.5	257.9	257.3
0.085	256.7	256.1	255.5	254.9	254.3	253.7	253.1	252.5	251.9	251.3
0.086	250.7	250.1	249.6	249.0	248.4	247.8	247.3	246.7	246.1	245.6
0.087	245.0	244.4	243.9	243.3	242.8	242.2	241.6	241.1	240.6	240.0
0.088	239.5	238.9	238.4	237.8	237.3	236.8	236.2	235.7	235.2	234.6
0.089	234.1	233.6	233.1	232.5	232.0	231.5	231.0	230.5	230.0	229.4
0.090	228.9	228.4	227.9	227.4	226.9	226.4	225.9	225.4	224.9	224.4
0.091	223.9	223.4	222.9	222.5	222.0	221.5	221.0	220.5	220.0	219.6
0.092	219.1	218.6	218.1	217.7	217.1	216.7	216.3	215.8	215.3	214.9
0.093	214.4	213.9	213.5	213.0	212.6	212.1	211.7	211.2	210.8	210.3

TABLE 2 *Continued*

Diagonal of Impression, mm	Vickers Hardness Number for Diagonal Measured to 0.0001 mm									
	0.0000	0.0001	0.0002	0.0003	0.0004	0.0005	0.0006	0.0007	0.0008	0.0009
0.094	209.9	209.4	209.0	208.5	208.1	207.6	207.2	206.8	206.3	205.9
0.095	205.5	205.0	204.6	204.2	203.8	203.3	202.9	202.5	202.1	201.6
0.096	201.2	200.8	200.4	200.0	199.5	199.1	198.7	198.3	197.9	197.5
0.097	197.1	196.7	196.3	195.9	195.5	195.1	194.7	194.3	193.9	193.5
0.098	193.1	192.7	192.3	191.9	191.5	191.1	190.7	190.4	190.0	189.6
0.099	189.2	188.8	188.4	188.1	187.7	187.3	186.9	186.6	186.2	185.5

At lower test forces the Vickers hardness may be force-dependent. In Table 2 are given the Vickers hardness numbers for a test force of 1 kgf. For obtaining hardness numbers when other test forces are used, the Vickers hardness number obtained from Table 2 is multiplied by the test force in kilograms-force (Table 3).

NOTE 1—The Vickers hardness number is followed by the symbol HV with a suffix number denoting the force and second suffix number indicating the duration of forceing when the latter differs from 10 to 15 s, which is the normal force time. *Example:*

440 HV 30 = Vickers hardness of 440 measured under a force of 30 kgf applied for 10 to 15 s.

440 HV 30/20 = Vickers hardness of 440 measured under a force of 30 kgf applied for 20 s.

TABLE 3 Decimal Point Finder for Use with Table 2
An example of determination of hardness numbers follows the table.

Diagonal Length, mm	Vickers Hardness (HV), 1-kgf Force
0.005	74 200
0.006	51 500
0.007	37 800
0.008	29 000
0.009	22 900
0.010	18 540
0.020	4 640
0.030	2 060
0.040	1 159
0.050	742
0.060	515
0.070	378
0.080	290
0.090	229
0.100	185.4
0.200	46.4
0.300	20.6
0.400	11.6
0.500	7.42
0.600	5.15
0.700	3.78
0.800	2.90
0.900	2.29
1.000	1.85
1.100	1.53
1.200	1.29
1.300	1.10
1.400	0.946
1.500	0.824
1.600	0.724
1.700	0.642
1.800	0.572
1.900	0.514
2.000	0.464

Example—Using a 50-kgf test force, the average measured diagonal length = 0.644 mm.

In Table 2 read:

HV = 447 at 0.0644-mm diagonal length at 1-kgf force.

Using Table 3 determine:

HV = 4.47 at 0.644-mm diagonal length at 1-kgf force.

50 × 4.47 = 224 HV for 50-kg test force.

A. GENERAL DESCRIPTION AND TEST PROCEDURE FOR VICKERS HARDNESS TESTS

4. Apparatus

4.1 *Testing Machine*—Equipment for Vickers hardness testing usually consists of a testing machine which supports the specimen and permits the indenter and the specimen to be brought into contact gradually and smoothly under a predetermined force, which is applied for a fixed period of time. The design of the machine should be such that no rocking or lateral movement of the indenter or specimen is permitted while the force is being applied or removed. A measuring microscope is usually mounted on the machine in such a manner that the impression in the specimen may be readily located in the optical field.

4.2 *Indenter*:

4.2.1 The indenter shall be a highly polished, pointed, square-based pyramidal diamond with face angles of 136° ± 30 min.

4.2.2 All four faces of the indenter shall be equally inclined to the axis of the indenter (within ±30 min) and meet at a sharp point, that is, the line of junction between opposite faces shall not be more than 0.001 mm in length as shown in Fig. 2.

4.2.3 The diamond should be examined periodically and if it is loose in the mounting material, chipped, or cracked, it should be discarded or reconditioned.

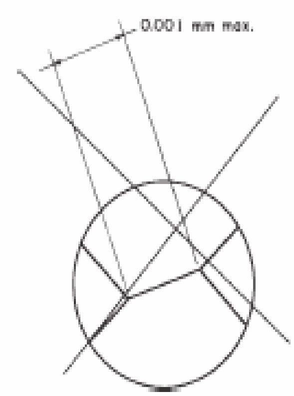

FIG. 2 Junction of Indenter Faces

NOTE 2—The condition of the point of the indenter is of considerable importance where the test force is light and the impression is small. It is recommended that the point be periodically checked by examining an impression made in a polished steel block. Under a magnification of 600× or more, using a vertical illuminator, any chipping or rounding of the point can be detected and the extent of the defect measured with a filar micrometer. It is recommended that a diamond pyramid indenter should not be used for tests in which the maximum length of such a defect exceeds 5 % of the length of the impression diagonal.

4.3 *Measuring Microscope*—The divisions of the micrometer scale of the measuring microscope or other measuring device shall be so constructed that the length of the diagonals of an impression in a properly surface-finished specimen (see section 5.1.2) can be measured to within ±0.0005 mm or ±0.5 %, whichever is larger.

5. Test Specimen

5.1 The Vickers hardness test is adaptable to a wide variety of test specimens ranging from large bars and rolled sections to minute pieces in metallographic mounts. In general the backs of the specimens shall be so finished or the specimens shall be so clamped that there is no possibility of their rocking or shifting under the test force. The specimens shall also conform to the requirements given in the following 5.1.1, 5.1.2, and 5.1.3.

5.1.1 *Thickness*—The thickness of the test specimen shall be such that no bulge or marking showing the effect of the force appears on the side of the specimen opposite the impression. In any event the thickness of the specimen shall be at least one and one half times the length of the diagonal. When laminated material is tested, the thickness of the individual component being tested shall be used for the thickness-diagonal length relationship.

5.1.2 *Finish*—The surface of the specimen should be so prepared that the ends of the diagonals are clearly defined and can be read with precision of ±0.0005 mm or ±0.5 % of the length of the diagonals, whichever is larger. Care should be taken in specimen preparation to avoid tempering during grinding, or work-hardening the surface during polishing.

5.1.3 *Alignment*—The specimen should be so prepared or mounted that the surface is normal to the axis of the indenter within ±1° of angle. This can readily be accomplished by surface grinding (or otherwise machining) the opposite side of the specimen to parallelism with the side to be tested.

5.1.4 *Radius of Curvature*—Until further investigative work is accomplished to determine the effect of the radius of curvature on readings, due caution should be used in interpreting or accepting the results of tests made on cylindrical surfaces.

NOTE 3—A method recommended by the International Organization for Standardization for correcting Vickers hardness readings taken on spherical or cylindrical surfaces is given in Table 4, Table 5, and Table 6.

NOTE 4—These tables give correction factors to be applied to Vickers hardness values obtained when tests are made on spherical or cylindrical surfaces. The correction factors are tabulated in terms of the ratio of the mean diagonal *d* of the indentation to the diameter *D* of the sphere or cylinder. Examples of the use of these tables are:

TABLE 4 Correction Factors for Use in Vickers Hardness Tests Made on Spherical Surfaces

Convex Surface		Concave Surface	
d/D^A	Correction Factor	d/D^A	Correction Factor
0.004	0.995	0.004	1.005
0.009	0.990	0.008	1.010
0.013	0.985	0.012	1.015
0.018	0.980	0.016	1.020
0.023	0.975	0.020	1.025
0.028	0.970	0.024	1.030
0.033	0.965	0.028	1.035
0.038	0.960	0.031	1.040
0.043	0.955	0.035	1.045
0.049	0.950	0.038	1.050
0.055	0.945	0.041	1.055
0.061	0.940	0.045	1.060
0.067	0.935	0.048	1.065
0.073	0.930	0.051	1.070
0.079	0.925	0.054	1.075
0.086	0.920	0.057	1.080
0.093	0.915	0.060	1.085
0.100	0.910	0.063	1.090
0.107	0.905	0.066	1.095
0.114	0.900	0.069	1.100
0.122	0.895	0.071	1.105
0.130	0.890	0.074	1.110
0.139	0.885	0.077	1.115
0.147	0.880	0.079	1.200
0.156	0.875	0.082	1.125
0.165	0.870	0.084	1.130
0.175	0.865	0.087	1.135
0.185	0.860	0.089	1.140
0.195	0.855	0.091	1.145
0.206	0.850	0.094	1.150

[A] *D* = diameter of sphere.
d = mean diagonal of impression in millimeters.

Example 1. Convex Sphere:	
Diameter of sphere, *D*	= 10 mm
Load	= 10 kgf
Mean diagonal of impression, *d*	= 0.150 mm
d/D = 0.150/10 = 0.015	
From Tables 2 and 3, HV	= 824
From Table 4, by interpolation, correction factor	= 0.983
Hardness of sphere = 824 × 0.983	= 810 HV 10
Example 2. Concave Cylinder, One Diagonal Parallel to Axis:	
Diameter of cylinder, D	= 5 mm
Load	= 30 kgf
Mean diagonal of impression, *d*	= 0.415 mm
d/D = 0.415/5 = 0.083	
From Tables 2 and 3, HV	= 323
From Table 6, correction factor	= 1.075
Hardness of cylinder = 323 × 1.075	= 347 HV 30.

6. Verification of Apparatus

6.1 The hardness testing machine shall be verified as specified in Part B.

6.1.1 Two acceptable methods of verifying Vickers hardness testing machines are given in Part B.

TABLE 5 Correction Factors for Use in Vickers Hardness Tests Made on Cylindrical Surfaces
(Diagonals at 45° to the axis)

Convex Surface		Concave Surface	
d/D[A]	Correction Factor	d/D[A]	Correction Factor
0.009	0.995	0.009	1.005
0.017	0.990	0.017	1.020
0.026	0.985	0.025	1.015
0.035	0.980	0.034	1.020
0.044	0.975	0.042	1.025
0.053	0.970	0.050	1.030
0.062	0.965	0.058	1.035
0.071	0.960	0.066	1.040
0.081	0.955	0.074	1.045
0.090	0.950	0.082	1.050
0.100	0.945	0.089	1.055
0.109	0.940	0.097	1.060
0.119	0.935	0.104	1.065
0.129	0.930	0.112	1.070
0.139	0.925	0.119	1.075
0.149	0.920	0.127	1.080
0.159	0.915	0.134	1.085
0.169	0.910	0.141	1.090
0.179	0.905	0.148	1.095
0.189	0.900	0.155	1.100
0.200	0.895	0.162	1.105
		0.169	1.110
		0.176	1.115
		0.183	1.120
		0.189	1.125
		0.196	1.130
		0.203	1.135
		0.209	1.140
		0.216	1.140
		0.222	1.150

[A] D = diameter of cylinder.
d = mean diagonal of impression in millimeters.

TABLE 6 Correction Factors for Use in Vickers Hardness Tests Made on Cylindrical Surfaces
(One diagonal parallel to axis)

Convex Surface		Concave Surface	
d/D[A]	Correction Factor	d/D[A]	Correction Factor
0.009	0.995	0.048	1.035
0.019	0.990	0.053	1.040
0.029	0.985	0.058	1.045
0.041	0.980	0.063	1.050
0.054	0.975	0.067	1.055
0.068	0.970	0.071	1.060
0.085	0.965	0.076	1.065
0.104	0.960	0.079	1.070
0.126	0.955	0.083	1.075
0.153	0.950	0.087	1.080
0.189	0.945	0.090	1.085
0.243	0.940	0.093	1.090
Concave Surface		0.097	1.095
		0.100	1.100
		0.103	1.105
d/D[A]	Correction Factor	0.105	1.110
		0.108	1.115
		0.111	1.120
0.008	1.005	0.113	1.125
0.016	1.020	0.116	1.130
0.023	1.015	0.118	1.135
0.030	1.020	0.120	1.140
0.036	1.025	0.123	1.145
0.042	1.030	0.125	1.150

[A] D = diameter of cylinder.
d = mean diagonal of impression in millimeters.

7. Procedure

7.1 *Magnitude of Test Force*—Test forces of 1 kgf to 120 kgf may be used, depending on the requirements of the test. Although tests on homogeneous materials indicate that the Vickers hardness number is nearly independent of the test force, this condition will not be present in cases where there is a hardness gradient from the specimen surface to the interior of the specimen. The magnitude of the test force should therefore be stated in the test report (Section 11).

7.2 *Application of Test Force*—Apply the test force and release smoothly without shock or vibration. The time of application of the full test force shall be 10 to 15 s, unless otherwise specified.

7.3 *Spacing of Indentations*—The center of the impression shall not be closer to any edge of the test specimen or to another impression than a distance equal to two and one half times the length of diagonal of the impression. When laminated material is tested, a bond surface shall be considered as an edge for spacing of indentation calculations.

8. Measurement of Impression

8.1 Both diagonals of the impression shall be measured and their mean value used as a basis for calculation of the Vickers hardness number. It is recommended that the measurement be made with the impression centered as nearly as possible in the field of the microscope.

8.2 In the case of anisotropic materials, for example materials that have been heavily cold worked, there may be a difference between the lengths of the two diagonals of the impression. In such cases, the test specimen should be reoriented so that the diagonals of a new impression are approximately of equal length.

9. Accuracy

9.1 The accuracy of the Vickers hardness method is a function of the accuracies of the test force, indenter, and measuring device. The condition of the test and support surfaces and support of the test piece during application of the test force also affect accuracy. Under optimum conditions of these factors the accuracy that can be expected is the equivalent of 4 % of the Vickers hardness number of the standardized reference hardness test blocks (see section 18.2). Under less than ideal conditions the reduction in accuracy, when required, can be established empirically by employing statistical methods.

10. Conversion to Other Hardness Scales or Tensile Strength Values

10.1 There is no general method for converting accurately Vickers hardness numbers to other hardness scales or tensile strength values. Such conversions are, at best, approximations and therefore should be avoided, except for special cases where a reliable basis for the approximate conversions has been obtained by comparison tests.

NOTE 5—Standard E 140 gives approximate conversion values for specific materials such as steel, nickel and high-nickel alloys, and cartridge brass.

11. Report

11.1 The report shall include the following information:

11.1.1 The Vickers hardness number,

11.1.2 The test force used (see 3.4.2, Note 1), and

11.1.3 The force application time, if other than 10 to 15 s (see 3.4.2, Note 1).

12. Precision and Bias

12.1 Due to the wide variety of materials tested by this method and the possible variations in test specimens, the precision of this method has not been established. The accepted practice is to utilize the information in 9.1 when establishing hardness tolerances for specific applications. The precision of this method, whether involving a single operator, multiple operators, or multiple laboratories, can be established by employing statistical methods.

B. VERIFICATION OF VICKERS HARDNESS TESTING MACHINES

13. Scope

13.1 Part B covers two procedures for the verification of Vickers hardness testing machines and a procedure that is recommended for use to confirm that the machine has not become maladjusted in the intervals between the periodical routine checks. The two methods of verification are:

13.1.1 Separate verification of force application, indenter, and measuring microscope.

13.1.2 Verification by standardized test block method.

13.2 The first procedure (13.1.1) is mandatory for new and rebuilt machines.

13.3 The second procedure (13.1.2) shall be used for verifying machines in service.

14. General Requirements

14.1 Before a Vickers hardness testing machine is verified the machine shall be examined to ensure that:

14.1.1 The machine is properly set up.

14.1.2 The indenter holder is mounted normally in the plunger.

14.1.3 The force can be applied and removed without shock or vibration in such a manner that the readings are not influenced.

14.2 If the measuring device is integral with the machine, the machine shall be examined to ensure that:

14.2.1 The change from forceing to measuring does not influence the readings.

14.2.2 The method of illumination does not affect the readings.

14.2.3 The center of the impression is in the center of the field of view.

15. Verification

15.1 *Separate Verification of Force Application, Indenter, and Measuring Microscope*:

15.1.1 *force Application*—The applied force shall be checked by the use of dead weights and proving levers, or by an elastic calibration device or springs in the manner described in Practices E 4. Such dead weights or other forceing devices shall be accurate to ±0.2 %. Vickers hardness testing machines shall be verified at a minimum of three applied forces including the test force specified. A minimum of three readings should be taken at each force. A Vickers hardness testing machine is acceptable for use over a forceing range within which the machine error does not exceed ±1 %.

15.1.2 *Indenter*—The form of the diamond indenter shall be verified by direct measurement of its shape or by measurements of its projection on a screen. The angle between opposite faces of the pyramid shall be 136° ± 30 min. All four faces shall be equally inclined to the axis of the pyramid within ±30 min. The four faces of indenters used for laboratory, or routine tests, shall meet at a point no more than 0.001 mm in length (see Fig. 2). The four faces of indenters used in calibrating standardized hardness test blocks, shall meet at a point in which the line of junction between opposite faces is no more than 0.0005 mm in length (see Fig. 3). The quadrilateral that would be formed by the intersection of the four faces with a plane perpendicular to the axis of the indenter shall have angles of 90° ± 12 min.

15.1.3 *Measuring Microscope*—The measuring microscope or other device for measuring the diagonals of the impression shall be calibrated against an accurately ruled line scale (stage micrometer). The errors of the line scale shall not exceed 0.05 µm (0.00005 mm) or 0.05 % of any interval, whichever is greater. The measuring microscope shall be calibrated throughout its range of use and a calibration factor chosen such that the error shall not exceed ±0.5 %. It may be necessary to divide the complete range of the micrometer microscope into several subranges, each having its own factor.

15.2 *Verification by Standardized Test Block Method*:

15.2.1 A Vickers hardness testing machine used only for routine testing may be checked by making a series of impressions on standardized hardness test blocks (Part C).

15.2.2 A minimum of five Vickers hardness readings shall be taken on at least three blocks having different levels of

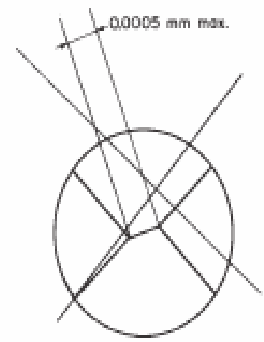

FIG. 3 Junction of Indenter Faces

hardness using a test force or forces as specified by the user with the test force applied for 12 s.

15.2.3 Vickers hardness testing machines shall be considered verified if the mean diagonal for five hardness impressions meets the requirements of 17.2.

16. Procedure for Periodic Checks by the User

16.1 Verification by the standardized test block method (15.2.2) is too lengthy for daily use. Instead the following is recommended:

16.1.1 Make at least one routine check each day that the testing machine is used.

16.1.2 Before making the check, verify that the zero reading of the measuring apparatus is correctly adjusted.

16.1.3 Make at least five hardness readings on a standardized hardness test block on the scale and at the hardness level at which the machine is being used. If the values fall within the range of the standardized hardness test block the machine may be regarded as satisfactory; if not the machine should be verified as described in 15.2.2.

17. Repeatability and Error

17.1 *Repeatability*:

17.1.1 For each standardized block, let $d_1, d_2, \cdots d_5$ be the arithmetic means of the two diagonals of the indentations, arranged in increasing order of magnitude.

17.1.2 The repeatability of the machine under the particular verification conditions is expressed by the quantity $d_5 - d_1$.

17.2 *Error*:

17.2.1 The error of the machine under the particular verification conditions is expressed by the quantity $\bar{d} - d$, where $\bar{d} = (d_1 + d_2 + \cdots d_5)/5$, and d is the reported mean diagonal of impressions on the standardized hardness test block.

18. Assessment of Verification

18.1 *Repeatability*—The repeatability of the machine verified is considered satisfactory if it satisfies the conditions given in Table 7.

18.2 *Error*—The mean diagonal for five impressions should not differ from the mean diagonal corresponding to the Vickers hardness of the standardized test block by more than 2 % or 0.5 µm (0.0005 mm), whichever is greater.

C. CALIBRATION OF STANDARD HARDNESS TEST BLOCKS FOR VICKERS HARDNESS MACHINES

19. Scope

19.1 Part C covers the calibration of standardized hardness test blocks for the verification of Vickers hardness testing machines as described in Part B.

TABLE 7 Repeatability of Machines

Range of Standardized Hardness of Test Blocks	The Repeatability of the Machine Should be Less Than:	Examples of Equivalents in Hardness Units
100 to 240, incl	4 % of d [A,B]	8 at 100 HV; 16 at 200 HV
Over 240 to 600, incl	3 % of d [A,B]	18 at 300 HV; 36 at 600 HV
Over 600	2 % of d [A,B]	28 at 700 HV

[A] $d = (d_1 + d_2 + ... + d_5)/5$.

[B] In all cases the repeatability is the percentage given or 1 µm (0.001 mm), whichever is the greater.

20. Manufacture

20.1 Each metal block to be standardized shall be not less than ¼ in. (6 mm) in thickness.

20.2 Each block shall be specially prepared and heat treated to give the necessary homogeneity and stability of structure.

20.3 Each block, if of steel, shall be demagnetized by the manufacturer and maintained demagnetized by the user.

20.4 The lower surface of the test block shall have a fine ground finish.

20.5 The test (upper) surface shall be polished and free of scratches which would interfere with measurements of the diagonals of the impression.

20.5.1 The mean surface roughness height rating shall not exceed 4 µin. (0.0001 mm) center line average.

20.6 To ensure that no material is subsequently removed from the test surface of the standardized test block, an official mark or the thickness at the time of calibration shall be marked on the test surface to an accuracy of ±0.005 in.(±0.1 mm).

21. Standardizing Procedure

21.1 The standardized hardness test blocks shall be calibrated on a Vickers hardness testing machine verified in accordance with the requirements of 13.1.1.

21.2 The mechanism that controls the application of force should either:

21.2.1 Employ a device such as a spring to reduce the velocity of indentation of the indenter during the period of indentation, or

21.2.2 Employ a device to maintain a constant velocity of indentation of the indenter.

21.3 The full test force shall be applied for 12 s.

22. Number of Indentations

22.1 At least five and preferably ten randomly distributed indentations shall be made on each test block.

23. Measurement of the Diagonals of the Indentation

23.1 The illuminating system of the measuring microscope shall be adjusted to give uniform intensity over the field of view and maximum contrast between the indentation and the undistributed surface of the block.

23.2 The measuring microscope shall be graduated to read 0.001 mm with estimates made to the nearest ±0.0002 mm.

23.3 The measuring microscope shall be checked by a stage micrometer, or by other suitable means, to ensure that the difference between readings corresponding to any two divisions of the instrument is correct within ± 0.0005 mm.

23.4 It is recommended that each indentation be measured by two observers.

24. Repeatability

24.1 Let $d_1, d_2, \cdots d_n$ be the mean values of the measured diagonals as determined by one observer, arranged in increasing order of magnitude.

24.2 The repeatability of the hardness readings on the block is defined as $(d_{10} - d_1)$, when ten readings have been made or 1.32 $(d_5 - d_1)$ when five readings are taken on the block.

25. Uniformity of Hardness

25.1 Unless the repeatability of hardness readings as measured by the mean diagonals of five or ten impressions is within the limits given in Table 8, the block cannot be regarded as sufficiently uniform for standardization purposes.

TABLE 8 Repeatability of Hardness Readings

Range of Standardized Hardness of Test Block	The Repeatability of the Test Block Readings Shall be Less Than:
100 to 240, incl	3 % of $d^{A,B}$
Over 240 to 600, incl	2 % of $d^{A,B}$
Over 600	1.5 % of $d^{A,B}$

[A] $d = (d_1 + d_2 + ... + d_n)/n$.

[B] In all cases the repeatability is the percentage given or 1 µm (0.001 mm), whichever is the greater.

26. Marking

26.1 Each block shall be marked with the following:

26.1.1 Arithmetic mean of the hardness values found in the standardization test (see also 3.4.2, Note 1).

26.1.2 The name or mark of the supplier,

26.1.3 The serial number of the block, and

26.1.4 The thickness of the test block or an official mark on the top surface (see section 19.6).

NOTE 6—All of the markings except the official mark or thickness should be placed on the side of the block, the markings being upright when the test surface is the upper face.

27. Keywords

27.1 metallic; Vickers hardness

Designation: E 407 – 99

Standard Practice for Microetching Metals and Alloys[1]

This standard is issued under the fixed designation E 407; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This practice covers chemical solutions and procedures to be used in etching metals and alloys for microscopic examination. Safety precautions and miscellaneous information are also included.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific cautionary statements, see 6.1 and Table 2.

2. Referenced Documents

2.1 *ASTM Standards:*

D 1193 Specification for Reagent Water[2]

E 7 Terminology Relating to Metallography[3]

3. Terminology

3.1 *Definitions:*

3.1.1 For definition of terms used in this standard, see Terminology E 7.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *tint etch*—an immersion etchant that produces color contrast, often selective to a particular constituent in the microstructure, due to a thin oxide, sulfide, molybdate, chromate or elemental selenium film on the polished surface that reveals the structure due to variations in light interference effects as a function of the film thickness (also called a "stain etch").

3.2.2 *vapor-deposition interference layer method*— a technique for producing enhanced contrast between microstructural constituents, usually in color, by thin films formed by vacuum deposition of a dielectric compound (such as ZnTe, ZnSe, TiO_2, ZnS or ZnO) with a known index of refraction, generally due to light interference effects (also known as the "Pepperhoff method").

4. Summary of Practice

4.1 Table 1 is an alphabetical listing of the metals (including rare earths) and their alloys for which etching information is available. For each metal and alloy, one or more etchant numbers and their corresponding use is indicated. Alloys are listed as a group or series when one or more etchants are common to the group or series. Specific alloys are listed only when necessary. When more than one etchant number is given for a particular use, they are usually given in order of preference. The numbers of electrolytic etchants are *italicized* to differentiate them from nonelectrolytic etchants.

4.2 Table 2 is a numerical listing of all the etchants referenced in Table 1 and includes the composition and general procedure to be followed for each etchant.

4.3 To use the tables, look up the metal or alloy of interest in Table 1 and note the etchant numbers corresponding to the results desired. The etchant composition and procedure is then located in Table 2 corresponding to the etchant number.

4.4 If the common name of an etchant is known (Marble's, Vilella's, etc.), and it is desired to know the composition, Table 3 contains an alphabetical listing of etchant names, each coded with a number corresponding to the etchant composition given in Table 2.

5. Significance and Use

5.1 This practice lists recommended methods and solutions for the etching of specimens for metallographic examination. Solutions are listed to highlight phases present in most major alloy systems.

6. Safety Precautions

6.1 Before using or mixing any chemicals, all product labels and pertinent Material Safety Data Sheets (MSDS) should be read and understood concerning all of the hazards and safety precautions to be observed. Users should be aware of the type of hazards involved in the use of all chemicals used, including those hazards that are immediate, long-term, visible, invisible, and with or without odors.

6.1.1 Consult the product labels and MSDSs for recommendations concerning proper protective clothing.

6.1.2 All chemicals are potentially dangerous. All persons using any etchants should be thoroughly familiar with all of the chemicals involved and the proper procedure for handling,

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[1] This practice is under the jurisdiction of ASTM Committee E-4 on Metallography and is the direct responsibility of Subcommittee E04.01 on Sampling, Specimen Preparation, and Photography.

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[2] *Annual Book of ASTM Standards*, Vol 11.01.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

mixing, and disposing of each chemical, as well as any combinations of those chemicals.

6.1.3 Table 2 includes specific safety precautions for the mixing or use of some etchants. The user should observe each of these specific precautions.

6.2 Some basic suggestions for the handling and disposing of etchants and their ingredients are as follows:

6.2.1 When pouring, mixing, or etching, always use the proper protective equipment (glasses, gloves, apron, etc.).

6.2.2 Use proper devices (glass or plastic) for weighing, mixing, containing, and storage of solutions.

6.2.3 When mixing etchants, always add reagents to the solvent unless specific instructions indicate otherwise.

6.2.4 When etching, always avoid direct physical contact with the etchant and specimen; use devices such as tongs to hold the specimen (and tufts of cotton, if used).

6.2.5 In general, it is good practice to work under a properly designed chemical fume hood, and it is imperative with those etchants that give off noxious odors or toxic vapors.

6.2.6 Methanol is a cumulative poison hazard. Where ethanol or methanol are listed as alternates, ethanol is the preferred solvent. Methanol should be used in a properly designed chemical fume hood.

TABLE 1 Etchants for Metals

NOTE 1—Electrolytic etchants are *italicized*.

Metal	Etchants	Uses
Aluminum Base:		
Pure Al	1a, 2, 3	general structure
	4, 5	grain structure under polarized light
	1b	grain boundaries and slip lines
1000 series	1a, 3, 2	general structure
	4, 5	grain structure under polarized light
	6, 7	phase identifications
2000 series	3, 2, 1a	general structure
	8a, 6, 7	phase identifications
3000 series	3, 1a	general structure
	4, 5	grain structure under polarized light
	8a, 6, 7	phase identifications
4000 series	3, 1a	general structure
5000 series	3, 1a, 2, 6, 8a	general structure
	4, 5	grain structure under polarized light
6000 series	3, 1a, 2, 6, 8a, 222	general structure
	4, 5	grain structure under polarized light
	1a, 2, 7, 6, 8a	phase identifications
7000 series	3, 1a, 2	general structure
	4, 5	grain structure under polarized light
	3b, 6	phase identifications
Beryllium Base:		
Pure Be	9, 10	general structure via polarized light
Be alloys	11	general structure
Chromium Base:	12, *13c*	general structure
Cobalt Base:		
Pure Co	14, 15, 16, 17	general structure
Hard-facing and tool metals	18, 19, 20	general structure
High-temperature alloys	20, 18, 16, 21, 22b, 24, 25	general structure
	19	phase identification
Columbium Base (see niobium base)		
Copper Base:		
Pure Cu	26, 27, 28, 29, 30, 31d, 32, 33, 34b, 35, 36, 37, 38, 39, 40, 41, 42, *8b*, 210, 215	general structure
	43, 28	chemical polish and etch
Cu-Al (aluminum bronze)	44, 31d, 34b, 35, 36, 37, 38, 39, 40, 45, 215	general structure
Cu-Be	46, 41, 45	general structure
Cu-Cr	41	general structure
Cu-Mn	41	general structure
Cu-Ni	34, 47, 48, 40, 49, 50	general structure

TABLE 1 *Continued*

Metal	Etchants	Uses
Fe + 15–30 Cr + 6–40 Ni + <5 % other elements (300 Series)	*13b*, 89, 87, 88, *83a*, 80, 94, 95, 91, 101, 212, 221, 226	general structure
	13a, *102*, 31c, 48c, 213	carbides and sensitization
and	*48*, *96*, *97*, 98	stains sigma phase
Fe + 16–25 Cr + 3–6 Ni + 5–10	103, 104, 98	delineates sigma phase and
Mn (200 series)	103, 104	welds of dissimilar metals
	86	chemical polish-etch
	219	grain boundary etch (no twins)
	220	darkens delta ferrite
High temperature	89, 25, 105, 106, *97*, *212*, *221*	general structure
	107, *108*, 213	γ′ precipitate
	86	chemical polish-etch
Nonstainless maraging steels	109, 89, 99, 100, 221	general structure
	83b	grain boundaries
	86	chemical polish-etch
Tool steels	74a, 80, 14	general structure
	110	grain boundaries in tempered tool steel
	210, 211	colors ferrite, lower alloy grades
	214, 214	colors cementite
	224, 225	carbides attacked and colored
Superalloys	86, 87, 94, 221, 226	general etch
	111	general structure
	111	γ′ depletion
Lead Base:		
Pure Pb	57, 112	general structure
	113	for alternate polishing and etching
Pb + <2 Sb	114, 115, 57, 74b	general structure
	113	for alternate polishing and etching
Pb + >2 Sb	114, 57, 74b	general structure
	113	for alternate polishing and etching
Pb + Ca	112	general structure
	113	for alternate polishing and etching
Pb alloys	116, 117b	general structure
Babbitt	74b	general structure
Magnesium Base:		
Pure Mg	118, 119, 74a, 120, 121, 122	general structure
	123	stain-free polish-etch
Mg-Mn	119, 74a, 124, 122	general structure
Mg-Al, Mg-Al-Zn (Al + Zn <5 %)	118, 119, 74a, 125, 124, *123*, 122	general structure
	120, 125, 126, 127	phase identification
	124, 126, 127	grain structure
Mg-Al, Mg-Al-Zn (Al + Zn >5 %)	118, 119, 74a, 125, 124, 121, 122	general structure
	120, 125, 126, 127	phase identification
Mg-Zn-Zr and	118, 119, 74a, 1d, 128, 124, 126, 127, 121, 122	general structure
Mg-Zn-Th-Zr	120, 121	phase identification
Mg-Th-Zr and	118, 119, 74a, 1d, 124, 127, 121, 122	general structure
Mg-Rare Earth-Zr	120, 121	phase identification
Molybdenum Base:	98c, 129, 130, *131*	general structure
As cast	132a	chemical polish prior to etching
Nickel Base:		
Pure Ni and high Ni alloys	133, 134, 47, 135, 136, 25, 108, 31c	general structure
	137	grain boundary sulfidation
Ni-Ag	38, 138, 50, 139	general structure
Ni-Al	*50*, 140, 141, *142*, 89, 143	general structure
Ni-Cr	144, 50, *83*, *134*, *145*, 98, 146, 147, *13a*	general structure
Ni-Cu	38, 138, 50, 133, 140, 25, *134*, 47, *48b*, 94, *108*, 34	general structure
Ni-Fe	*50*, 140, 141, *83*, *134*, 148, 40, 107, 149	general structure
	74e, 25, 150	orientation pitting
Ni-Mn	74e	general structure
Ni-Mo	143	general structure
Ni-Ti	143, 151, 50, 133	general structure
Ni-Zn	152	general structure

TABLE 2 *Continued*

Etchant	Composition	Procedure
60	25 mL HNO_3 15 mL acetic acid 15 mL HF 5–7 drops bromine	Use hood. Let stand ½ h before using. Swab 3–20 s.
61	60 mL HCl 40 mL HNO_3	Use hood. Immerse few seconds to a minute.
62	1–5 g CrO_3 100 mL HCl	Vary composition of reagent and aging of reagent after mixing to suit alloy. Swab or immerse few seconds to a minute.
63	0.1 g CrO_3 10 mL HNO_3 100 mL HCl	Swab few seconds to a minute.
64	5 mL HNO_3 25 mL HCl 30 mL water	(a) Immerse 1–5 min. (b) Use hot. Will form chloride film on gold alloys if much silver is present. Ammonia will remove film.
65	A 10 g ammonium persulfate 100 mL water B 10 g KCN 100 mL water	Use hood—Can give off extremely poisonous hydrogen cyanide. Precaution—Also poisonous by ingestion as well as contact. Mix 1 + 1 mixture of Solutions A and B just before use. (A mixture of 5 drops of each will cover the surface of a 1 in. dia. mount.) Immerse ½ – 2 min.
66	30 mL HF 15 mL HNO_3 30 mL HCl	Swab 3–10 s or immerse to 2 min.
67	10 mL perchloric acid 10 mL 2-butoxyethanol 70 mL ethanol (95 %) 10 mL water	Precaution—Keep cool when mixing and use. Electrolytic at 30–65 V for 10–60 s.
68	3 mL perchloric acid 35 mL 2-butoxyethanol 60 mL methanol (absolute)	Precaution—Keep cool when mixing and use. Electrolytic at 60–150 V for 5–30 s.
69	5 mL perchloric acid 80 mL acetic acid	Precaution—Keep cool when mixing and use. Electrolytic at 20–60 V for 1–5 min.
70	5 mL HF 2 mL $AgNO_3$ (5 %) 200 mL water	Swab for 5–60 s.
71	5 mL HF 95 mL water	Add 5–10 drops of this solution on the final polishing wheel which has been charged with the polishing solution. The specimen is polished on this wheel until the surface turns black. Distilled water is then slowly added to the wheel and polishing continued until the surface is bright. At this time the specimen should be ready for examination via polarized light. Note—Use inert substance between cloth and wheel to prevent attack of the wheel. Wear gloves.
72	10 mL HF 45 mL HNO_3 45 mL water	Swab for 5–20 s.
73	20 mL HCl 25 g NaCl 65 mL water	Electrolytic etch—use carbon cathode and platinum wire connection to specimen. (a) 6 V ac for 1 min. (b) 5 V–20 V ac for 1–2 min. (c) 20 V ac for 1–2 min. For etch-polishing, use shorter times. After etching, water rinse, alcohol rinse, and dry.
74	1–5 mL HNO_3 100 mL ethanol (95 %) or methanol (95 %)	Etching rate is increased, sensitivity decreased with increased percentage of HNO_3. (a) Immerse few seconds to a minute. (b) Immerse 5–40 s in 5 % HNO_3 solution. To remove stain, immerse 25 s in 10 % HCl-methanol solution. (c) For Inconels and Nimonics, use 5 mL HNO_3 solution—electrolytic at 5–10 V for 5–20 s. (d) Swab or immerse several minutes. (e) Swab 5–60 s. HNO_3 may be increased to 30 mL in methanol only depending on alloy. (Ethanol is unstable with over 5 % HNO_3.) Do not store.
75	5 g picric acid 8 g $CuCl_2$ 20 mL HCl 200 mL ethanol (95 %) or methanol (95 %)	Immerse 1–2 s at a time and immediately rinse with methanol. Repeat as often as necessary. (Long immersion times will result in copper deposition on surface.)